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THESIS

EVALUATING OPERATIONAL MANEUVER IN A COMPUTER AIDED EXERCISE

by

Kevin P. Brown

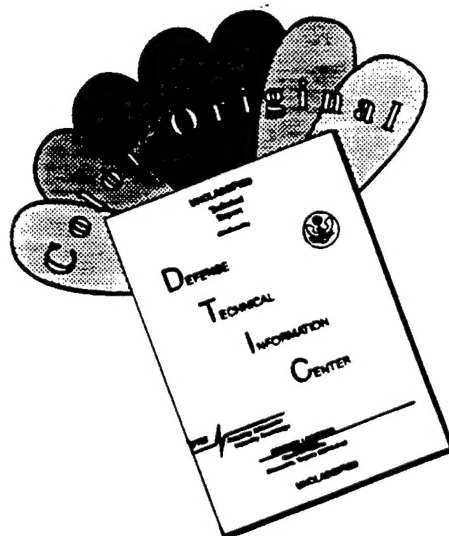September 1996

Thesis Advisor: Sam Parry

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13. ABSTRACT *(maximum 200 words)*

The development of proficient Joint Staffs at the Joint Task Force level is receiving increased emphasis. One of the primary training tools available is the use of computer aided exercises. In utilizing these devices for training Joint Task Force Staffs, many observations can be made over the course of the exercise which aid in assessing readiness. The primary document used to focus the training and assessment effort is the Universal Joint Task List. The list provides both the staff and evaluators with a common document outlining critical events and activities which require successful accomplishment. The document is organized in a manner which defines activities associated with the many functional areas of staff activity including logistics, intelligence, force protection, and operational firepower planning.

It is the purpose of this thesis to provide a methodology for objectively assessing the staff's ability to conduct operational maneuver. Experimental runs using the Joint Theater Level Simulation demonstrate how critical events and command control decisions affect the tempo of battle and produce data elements which are useful in developing measures of performance for operational maneuver.

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EVALUATING OPERATIONAL MANEUVER IN A COMPUTER AIDED EXERCISE

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requirements for the degree of

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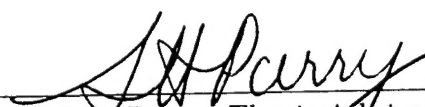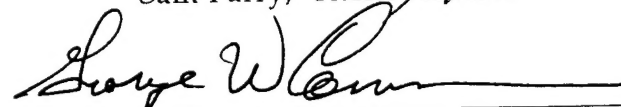
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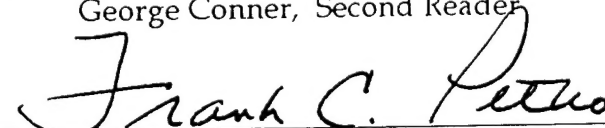
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ABSTRACT

The development of proficient Joint Staffs at the Joint Task Force level is receiving increased emphasis. One of the primary training tools available is the use of computer aided exercises. In utilizing these devices for training Joint Task Force Staffs, many observations can be made over the course of the exercise which aid in assessing readiness. The primary document used to focus the training and assessment effort is the Universal Joint Task List. The list provides both the staff and evaluators with a common document outlining critical events and activities which require successful accomplishment. The document is organized in a manner which defines activities associated with the many functional areas of staff activity including logistics, intelligence, force protection, and operational firepower planning.

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EXECUTIVE SUMMARY

Readiness at all levels of command in all services is the ultimate focus of training. While the training effort has the necessary focus at the service levels, the joint training process is still in its infancy. This thesis presents a methodology for assisting the assessment of joint staff performance during a Computer Aided Exercise (CAX) with respect to one of many battlefield functional areas, Operational Maneuver.

For forces at the brigade and battalion level the Combat Training Centers are equipped and manned at the highest level to insure a valuable training experience. One of the most valuable products of a training rotation at one of those locations is the After Action Review process. Immediate feedback is given with respect to understood tasks which, given certain conditions, are to be performed to a required standard. The units are provided with a wide range of paper copy and multimedia documentation of unit performance. The critical aspect of this information is that it assists in focusing the training effort. In the years of a declining defense budget training time must be optimized to increase readiness on those tasks identified as weaknesses.

The burden on readiness caused by the lack of continuity in joint staff make-up is compounded by the fact that lessons learned from joint exercises are not captured as efficiently as at lower levels. This results in a weakened learning process from exercise to exercise. Currently, the primary method of

archiving observations is the use of the Joint Universal Lessons Learned System. The observations are not always a measure of warfighting readiness, but rather a measure of the administrative conduct of the exercise. To help focus the training effort the Universal Joint Task List (UJTL) was developed. This document aligns with the task, condition and standard method of training, assessment and retraining used at lower levels of command.

The primary method of training a joint staff is the use of a Computer Aided Exercise (CAX). The primary role of the underlying computer simulation is to present a decision environment to the staff that produces realistic, stochastic results. Based on this simulated environment, staffs implement plans, monitor the current situation, and further develop or alter plans as required by the changing requirements.

The objective of this thesis is to develop an exercise analysis methodology for evaluating joint staff performance of maneuver oriented UJTL tasks in a CAX. Specific objectives are:

- Determine quantifiable measures of effectiveness (MOEs) designed to work in conjunction with data manipulated by a futuristic computer simulation.

- Ensure the measures reflect the underlying doctrinal concepts of maneuver as defined in joint and service training manuals.

- Test the measures of effectiveness using the Joint Theater Level Simulation (JTLS). This includes the development of a potential post-exercise analysis technique for data currently captured in standardized ASCII files.

The interested reader is referred to the Naval Postgraduate School Technical Report entitled *Evaluation of Functional Area Performance in Internal Look 96*, for a practical application of these methodologies in analyzing a Central Command exercise.

Utilizing these objectives, this thesis investigates the effects of maneuver on the battlefield. The critical data elements involve parameters describing the capability, or mass, of forces and their relative velocities. This provides for the demonstration of some physical analogs to help describe the processes of military momentum, force and pressure. These concepts help quantify the art of war and assist in observing the second order effects of command and control decisions and successes or failures in other battlefield functional areas. With the quantifiable measures developed here, the after action review process will be more objective and perhaps enhance the learning during and after a CAX.

ACKNOWLEDGEMENT

I am forever grateful to my advisor, Professor Sam Parry, for encouraging me to think like a warrior in the midst of completing a master's degree in operations research. I would also like to thank Captain Frank Petho, USN for motivating me to do the right thing and supporting me in my quest. Finally, I extend my thanks to my family and friends for always being ready to lend a hand or encouragement along the way.

I. INTRODUCTION

A. PROBLEM STATEMENT

The operational level of war, the primary focus of evaluation in this thesis, serves as a link between the tactical and strategic levels. The increased emphasis on joint operations puts a higher premium on flawless execution at the operational level than ever before. The difficulty in assessing operational performance resides in the lack of definition of measurable operational tasks. Data wealthy tactical battles provide useful information, but only if their results are integrated to provide an overall operational measure. It is the goal of this thesis to provide a methodology for extracting the appropriate data from a computer aided exercise (CAX) in order to make maneuver warfare concepts tangible and measurable at the operational level. This will assist the creation of measures of effectiveness and performance for operational level staffs. The results of a CAX will then be more readily available for historical trend analysis and immediate feedback.

B. SUPPORTING EFFORTS

This thesis supports a research effort directed at providing measurable feedback with respect to the Universal Joint Task List (UJTL). The UJTL identifies key mission requirements and is the yardstick by which the Chairman of the Joint Chiefs of Staff can measure readiness. The overall use of the UJTL is discussed further in Chapter II. The framework of the UJTL derives from the

United States Army Blueprint of the Battlefield, which divides all operations on the battlefield into functional areas. This thesis is a step toward providing measures for those UJTL tasks pertaining to the conduct of Operational Maneuver. This work must be viewed, however, as a part of the whole effort of evaluating the overall readiness of a Joint Staff. The work of other thesis students will address functional areas regarding force protection, operational firepower and short term logistics support of amphibious operations. Work has already been completed which developed measures of performance for theater logistics and intelligence tasks. The interested reader is referred to the Naval Postgraduate School Technical Report entitled *Evaluation of Functional Area Performance in Internal Look 96*, for a practical application of these methodologies in analyzing a Central Command exercise.

Taken together, these theses represent the baseline for further efforts to develop a standard evaluation methodology for Joint Staff performance. The conduct of a CAX produces a realistic environment for the training of a Joint Staff. The use of the standardized methods for evaluating data developed in these papers will assist in quantifying the training readiness state of a Joint Staff. The method of analysis described in these papers provides a technique for developing a causal audit trail for success or failure by a Joint Staff being trained in a CAX.

C. OVERVIEW

The next chapter will provide background information on the three key vehicles for the development of this thesis: the UJTL, Operational Maneuver concepts, and theater level computer aided simulations. First, the UJTL is described as the medium by which battlefield events or tasks can be defined for assessment. This description will focus on the use of the UJTL in training the force. The utility of a common document for all Unified Commands is critical to standardizing the overall process of preparing, assessing, and training all joint forces.

The military concepts of Operational Maneuver are then discussed in order to identify the key areas which cause a force to succeed or fail on the battlefield in this particular functional area. In gaining an understanding of the military theory, the difficulty of trying to quantitatively assess concepts such as *principles* and *tenets* becomes apparent. Additionally, an attempt is made to identify tangible measures of some of the more intangible aspects of the conduct of war. While many battlefield functions are quite measurable, maneuver is the end result of command and control and the human decision making process. To that end, analysis will be conducted on maneuver characteristics tied to command and control decisions. Finally, theater level simulations are described as the tool which allows the capture of actual data to support the methodology.

In Chapter III, each of the vehicles for analysis mentioned above are described in greater detail. The methodology is traced from the input provided by the UJTL. The important concepts of maneuver, which can be likened to the function to be analyzed, are described next. Finally, the output of data provided by the Joint Level Theater Simulation (JTLS) is described. This is summarized in a dendritic which links critical issues with the data required to assess those issues.

First, the hierarchical structure of the UJTL is shown along with the integrated link between the other functional areas being addressed in other theses. This demonstrates the complementary aspect of this work in assessing the overall readiness of a staff.

Secondly, the identification of measurable battlefield activities is discussed, where maneuver aspects such as agility and initiative are given a more calculable definition for assessment. From the identification of these measurable activities the formulation of measures of performance is presented. Finally, the JTLS database information and management of that information is described to understand how the simulation executes maneuver. JTLS representations contain the necessary variables to describe systems and states of nature in the attack. However, the simulation itself does not represent the effects of maneuver. These effects are a result of command and control decisions made during the conduct of an interactive wargame. Therefore, an example is

introduced to demonstrate application of the methodology and its relation to player decisions. Spreadsheet and Pascal implementations used for data analysis are described to complete this discussion.

The conduct of experimental and actual JTLS runs is discussed in Chapter IV. Background information is provided to describe how JTLS algorithms accomplish the various maneuver tasks. The scenarios used in the controlled runs and the resulting outputs for analysis are shown. Finally, trends and issues are identified and conclusions as to the significance of the results are offered. In Chapter V, recommendations are given in order to further the study and advance this methodology to a more integrated measure involving all functional areas being analyzed. Additionally, the possibility of using the methods introduced here to induce maneuver effects into modeling is explored.

II. BACKGROUND

A. JOINT TRAINING PROCESS

The Universal Joint Task List, or UJTL, is being utilized by all unified commands to assist in mission planning and ensures a common use of military doctrinal language among all services. The document has been in development for nearly two years with the most current version dated 15 May 1995. The overall proponent for the UJTL is the Chairman of the Joint Chiefs of Staff, with responsibility residing with the J-7 Directorate. The J-7 staff expected the completed version of the task list to be available for use in December of 1995, but does not expect the list to be integrated into exercises until fiscal year 1998. The major tasks to be evaluated at the strategic (both national and theater), operational, and tactical levels of war are outlined in Figure 1.
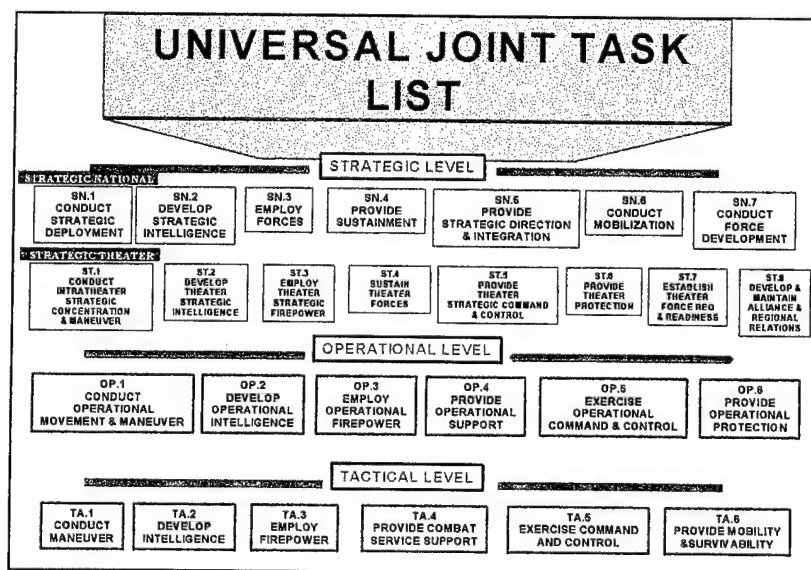
Figure 1. Base structure of the UJTL (Source: JWFC Command Brief).

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The Universal Joint Task List is an integral part of the overall process of evaluating joint readiness. Figure 2 demonstrates the cyclic process used to develop doctrine, determine training requirements, and assess the level of training.
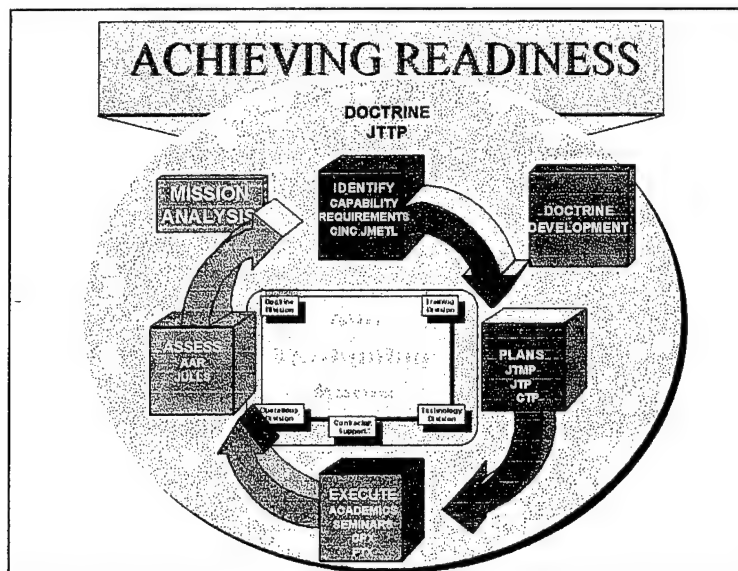
Figure 2. The Training and Readiness Loop (Source: JWFC Command Brief)

The cycle is modeled after the process introduced by Colonel John Boyd of the United States Air Force for understanding the development of a potential combat situation. The process, known as the Observation, Orientation, Decision, and Action Loop, serves here to insure a link between observed capabilities and requirements for a particular CINC and development of a training exercise measuring that command's ability to fight and win.

A 1995 report by the General Accounting Office noted that on many occasions the training goals currently set for the accomplishment of a joint

training exercise provided no real measure of capability or readiness [Ref. 1: p. 3:2]. Instead, success was measured by goals which only represented participation and administrative execution of the exercise. Utilizing the tasks from Figure 1, the process from Figure 2, and the measures introduced here, a more useful analysis can be derived from computer aided exercises. This will focus the orientation and direction part of the Boyd cycle and lead to a more refined assessment of areas needing more emphasis and training in the development of follow-on exercises.

The product of this thesis, in conjunction with the theses covering other operational tasks, will assist in providing direct integration of UJTL standards into the exercise. Also, these efforts will assist in facilitating rapid analysis of the level of training of a Joint Staff.

B. GROUND MANEUVER

> *Battles are won by slaughter and manoeuvre. The greater the general, the more he contributes in manoeuvre, the less he demands in slaughter.*
> -Winston Churchill

Both Naval Doctrinal Publication 1 and Marine FMFM 1, Warfighting, address two types of warfare: attrition and maneuver. The underlying theme of attrition warfare is strength against strength in an attempt to destroy enemy personnel and equipment. Maneuver warfare, on the other hand, focuses on gaining a positional advantage or exploiting a tactical advantage. The positional

advantage is with respect to both time and space; that is, we generate a faster operational tempo than that of the enemy to gain a temporal advantage. [Ref. 2: 58] Before going further it is critical to point out the similarities and differences of tactical and operational maneuver. The interdependence of tactical fire and maneuver is critical; one cannot take place without the other.

While that interdependence still exists at the operational level, maneuver at this level is the movement that establishes the conditions to discharge combat power. It is therefore feasible to measure maneuver with regard only to the combat *potential* of the force conducting the maneuver rather than the actual attrition it is presently causing. The preconditions for an attrition fight are set as a result of the completion of successful maneuver. It is the goal here to determine the effects of operational maneuver. This does not translate directly to the effects of fire, but to the effects of deploying forces for gain, either in a coming battle or by taking an objective for which the enemy does not or will not fight.

The results of attrition warfare are quantifiable and obtainable and, therefore, normally used when analyzing historical battles or computer simulations. Data elements such as the relative loss of personnel and equipment for friendly and enemy forces seem to be reasonable measures for determining success on the battlefield. Developments in combat modeling over the last half of the century have been directed towards the approach that, given a believable

set of attrition rates, the outcome of an engagement can be anticipated. History seems to demonstrate that the resolve of the defeated force was typically destroyed by other causes, primarily maneuver. [Ref. 3]   Care should be taken in using these data, however, as attrition warfare is synonymous to "slaughter" from the quote by Churchill. Attrition results that appear less than favorable may therefore lead to false conclusions that a campaign was less than successful. In light of what Churchill says, perhaps "poor" attrition warfare results are actually countered by *successful* maneuver results.   It is therefore necessary to capture measures of performance that assess the attributes of maneuver warfare to ensure that a well planned maneuver strategy is not assessed using easily gathered, but inappropriate attrition data elements. Perhaps Robert Leonhard says it best in his book, The Art of Maneuver:

> *Rather than always resorting to expressing simulation results in terms of kill rates and loss ratios, we should seek to paint a more comprehensive picture of the factors that make up victory or defeat. We should routinely think in terms of movement speeds, decision points, intelligence, command and control, deception, suppression, and morale. When we begin to speak in terms of these new measures of effectiveness, we will begin to shape our design of the future force into a more maneuver-oriented combat team. More important, we will be aligning our simulations with battlefield realities instead of with analytically useful fiction.*[Ref. 4: p.143]

The capstone Army manual, FM 100-5, Operations, makes no distinction between attrition and maneuver warfare. Instead, the Army relies on doctrinal terms to describe the characteristics of a successful operation. These terms are the Tenets of Army Operations: agility, initiative, depth, synchronization, and

versatility.   Each of these tenets will be briefly outlined with a general attempt at quantifying certain aspects of each. For each aspect addressed, there are many more characteristics that could be considered necessary; however, the discussion will be limited to a few of the more measurable.

Agility and versatility measure the ability of a force to seize the initiative quicker and transition faster on the battlefield than the enemy.   This requires both physical and mental agility. Efficient command and control will insure that the right forces are moving at the right time to the right location.   Making operational use of the Boyd Loop described in Chapter I, this likens to breaking the enemy's Boyd Loop at the decision point while simultaneously accelerating your own decision process. This concept is demonstrated graphically below:

Breaking the OODA Loop

ENEMY   FRIENDLY

OBSERVE   OBSERVE

ACT   ORIENT   ACT   ORIENT

DECIDE   DECIDE

GOAL: Cycle faster than the enemy and break into his loop at the earliest phase possible/allowable

MEANS: **Information Differential** translated to a **Closure Differential** or **Firepower Differential**
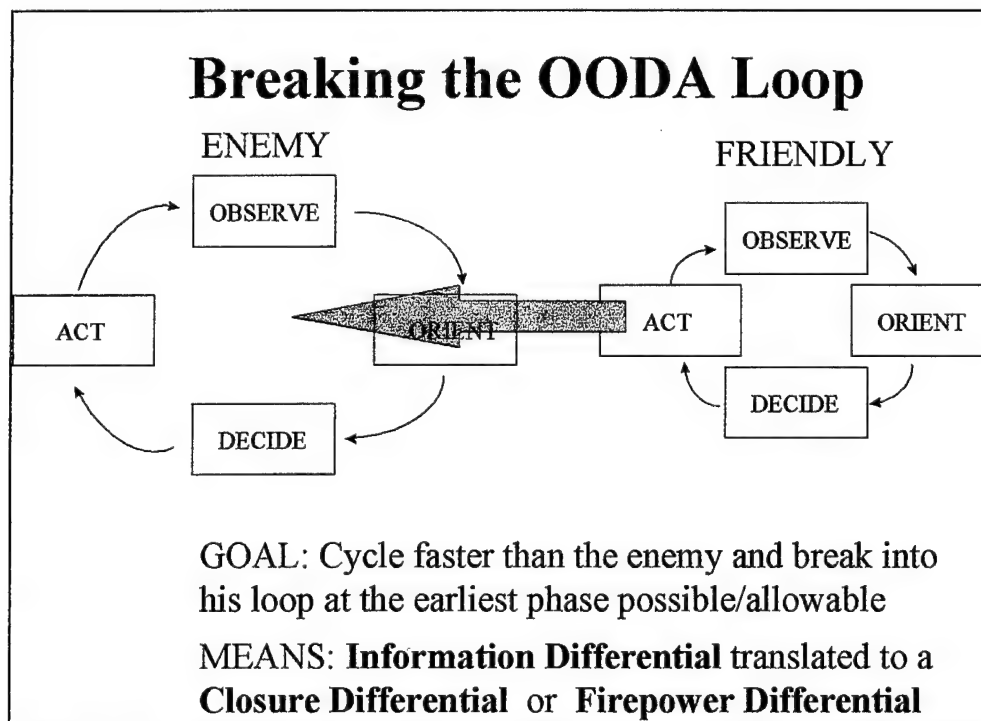
Figure 3. Effects of C² on Closure Differential.

To make this aspect of maneuver warfare easily measurable, one could analyze the difference in time between transitions to new operations and the time spent in particular mission postures. Furthermore, weigh the amount of success achieved by analyzing the strength of the force during those transitions and in each potential posture. Quantitatively, the time spent between transitions could be viewed as a measure of agility, if rapid transitions equated to victories on the battlefield. Conversely, rapid transitions could identify a force that is always reacting to enemy actions. In either case the data are relevant and should be made available for the decision maker to determine what is an acceptable level of dynamic or static postures. This analysis can be used when assessing the ability of a force to create the proper tempo without radical changes in posture.

Initiative in the attack involves pressing the fight and maintaining the position of advantage over the enemy. By concentrating strengths against enemy vulnerabilities and maintaining the speed of the attack, an attacker can maintain the initiative. The greater the number of available, uncommitted forces a commander has at his disposal, the greater the opportunity to maintain the initiative. To measure this aspect of maneuver, consider the number of enemy forces a friendly force is engaging with the intent of suppression or containment. If this has occurred with a minimal use of friendly forces, the

commander has maintained the initiative much more clearly than if he had equaled the amount of forces his enemy committed to action.

Depth of the attack and synchronization both measure the ability of the commander to bring the effects of fire and maneuver on the enemy throughout the battlespace and require coordination of assets from all services. These aspects could be best described by the ability of a friendly force to maneuver at great distances while taking few casualties and inflicting maximum damage to the material, equipment, and command and control of the enemy. The overall ability to close the battle at any time, from any distance, using any asset will be measured by a closure differential which demonstrates the physical momentum, acceleration and leverage of the attacking force.

Leonhard points out three critical goals of maneuver warfare: preemption, dislocation, and disruption.[Ref. 4] These terms are extensions of the Tenets of Army Operations and support the collection of very similar objective data in analyzing maneuver warfare. In acting with more agility and initiative than the enemy, a friendly commander can force the enemy to continuously transition his forces from one mission to the next. In this way the friendly force is causing the expenditure of excess energy and logistical support as the enemy attempts to determine his best counter to friendly action. The underlying philosophy of maneuver warfare is to shatter the enemy's desire to fight. By conducting

preemptive dominant maneuver and disrupting the enemy decision cycle with rapid action, this goal can be achieved.

These doctrinal and somewhat intangible terms are the underpinnings of the argument that maneuver warfare is an art and not a science, and therefore not measurable when compared to attrition warfare. The operational level of war, the primary focus of evaluation in this thesis, serves as a link between the tactical and strategic levels. Tactical battles provide useful data, but only if their results are integrated to provide an overall operational measure. The methods described here will provide ways of extracting measurable quantities from a computer aided exercise that make maneuver warfare concepts tangible.

C. SYNTHESIZING TACTICAL AND OPERATIONAL RESULTS

Currently, Cubic Applications is working under government contract at the Joint Warfighting Center to provide data analysis in support of the after action review (AAR) process. Their data analysis involves capturing useful data elements such as the number of systems available of a certain type or the number of systems lost to a particular type of munitions. These types of results are tactical in nature and quantify the end state of any number of battles or engagements. According to FM 100-5, without operational art, *war* would be a set of disconnected engagements, with relative attrition the only measure of success or failure [Ref. 5: p. 6-2]. Similarly, without assessment of operational

level tasks, *analysis* will be only a set of disconnected measures of tactical results.

In addition to Cubic's data analysis processes, the Joint Universal Lessons Learned System (JULLS) is currently utilized to capture and archive written observations made during the conduct of a joint exercise. These observations can be made at the operational level of war but currently have no quantitative measures which support the findings and subjective comments. The goal, then, is to synthesize the tactical results that Cubic and others are currently gathering with a measure of operational aspects in order to assess performance at the operational level and support written observations currently archived in the JULLS.

D. JOINT THEATER LEVEL MODELING

One of the factors involved in the development of a computer aided exercise is selection of the appropriate model. The selection of the model is often driven by the objectives of the training exercise, since each model has its own limitations on what can be represented. The two most common simulation configurations in use today are the Confederation of Models, which joins together the service specific simulation models, and the Joint Theater Level Simulation. While there also exist many analytical models which require no human interaction, these models can not capture the effects of human decision processes which is at the core of maneuver warfare and command and control.

The Confederation of Models is a structure which integrates the existing service specific models through the use of a layer of software called Aggregate Level Simulation Protocol (ALSP). ALSP interprets and delivers situational updates and combat attrition results between models that use differing internal techniques. One of the advantages of this configuration is the resolution provided by the service specific models in simulating the particular capabilities of the components and other supporting structures such as national intelligence and global communications systems. There is some loss of clarity, however, when the ALSP cannot infer the proper picture from conflicting data across all component systems. Additionally, the two-sided nature of the service models prevents the inclusion of coalition forces. Coalition warfare has become a common characteristic of most joint operations and an integral part of analyzing operational maneuver, especially considering the difficult command and control structure.

The Joint Theater Level Simulation is an interactive multi-sided, aggregated, low resolution model designed to simulate air, ground and sea conflict in an area of operations of 2000 by 2000 square nautical miles. When used to support analysis of operation plans, JTLS affords several advantages over models that rely on attrition of units based on combat power within specified movement corridors. The JTLS model provides better fidelity than ALSP, allows introduction of the effects of maneuver warfare, allows dynamic

application of air and naval power, and provides functions to model special operations. [Ref. 6: p I]. Additionally JTLS maintains documentation of how functional areas interact throughout the game. The capability to capture useful data from that documentation is critical to this analysis. Finally, JTLS has been selected by NATO to serve as the standard for joint computer aided exercises, making it the preferred model for the conduct of this analysis.

III. METHODOLOGY

A. DEVELOPMENT OF MEASURES

The conduct of operational level maneuver is dependent upon the execution of movement and maneuver tasks at the other levels of war. Likewise, the performance of operational maneuver will affect the results of movement and maneuver at those other levels. This highlights the vertical linkage of tasks within a functional area as shown in Figure 4. The aim or objective which places a force at a particular level of war may result in subordinate aims or objectives for a portion of that force, with tasks at a lower level of war. A theater of operations commander, or regional Commander in Chief, operates most often at the operational level of war by applying military power in a designated theater of operations. The efforts at that level support the strategic objectives assigned by a geographic combatant commander or the national command authority. [Ref. 7: pp. 2-3,4]

The interdependence of each battlefield functional area has been emphasized. The horizontal linkage across the entirety of the UJTL is represented in Figure 5, highlighting the most critical tasks from other functional areas which affect the accomplishment of movement tasks in a Humanitarian Relief mission. The effect of accomplishing these tasks manifests itself in the successful accomplishment of maneuver. Dynamics Research Corporation (DRC) has been developing measures and standards by which to define
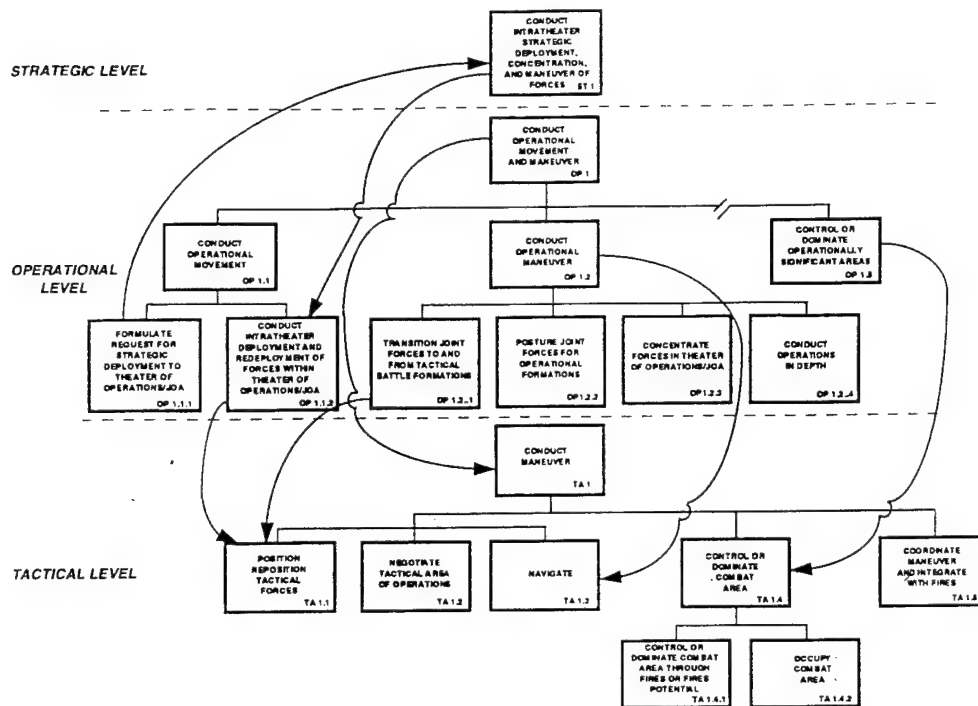
Figure 4. Vertical Linkage of Movement/Maneuver Tasks.
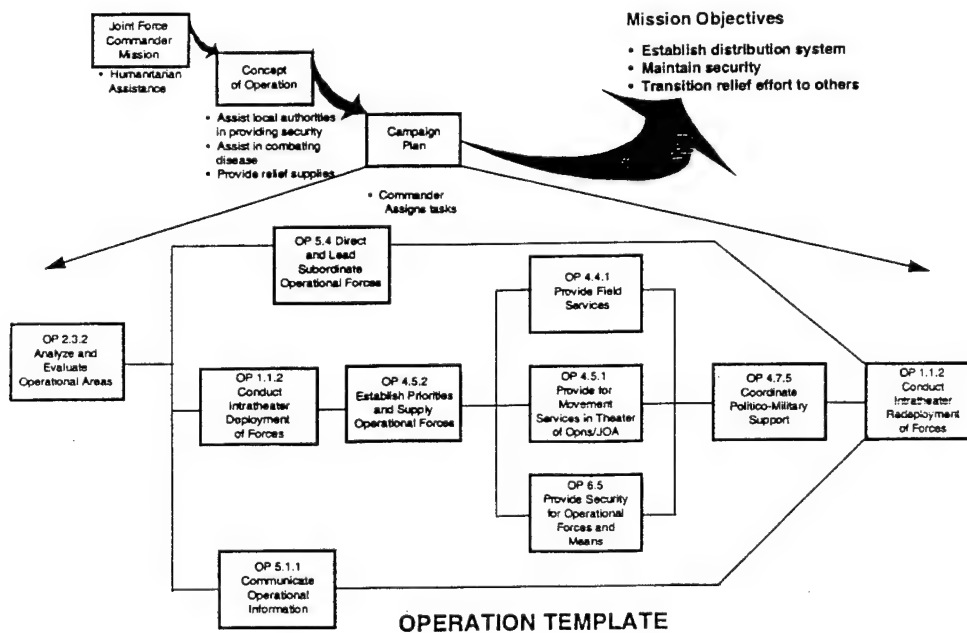
Figure 5. Horizontal Linkage Demonstrated in a Humanitarian Assistance Mission.

successful accomplishment of all tasks in the UJTL. This effort was useful in determining a starting point for this study.

The DRC has developed a software package called the Joint Training Computerized Analysis Tool (JoinT-CAT). A Joint Staff can select the essential tasks for training and readiness and input the desired performance level for any number of measures associated with a task. These measures are effective for identifying quantities which can be described in terms of the percentages of the whole force conducting some activity. For movement and maneuver the standards normally relate to the actual velocity of forces or the rate at which they are deployed. The users manual for the JoinT-CAT software package defines three distinct parts of a *training standard*: a criterion, a scale and a measure. An example is shown below:

60	days	to complete mobilization
(criterion)	**(scale)**	**(measure)**

The manual states that the criterion and scale establish minimum or desired levels of performance. The measure is considered the basis for describing varying levels of performance with respect to UJTL tasks. The measure must be related directly to a task and there may be more than one measure for any task. [Ref. 8: p. 40] In some instances there is reference to the doctrinal concepts of the decisive point and surprise within the measures. The difficulty arises in determining how to collect these data elements. The dendritic in Figure 6 demonstrates the link between the major issue and the sub issues.

Figure 6. Dendritic for developing data requirements.

The diagram contains the following structure:

Issue
How well is Operational Maneuver being controlled and conducted?

Sub-issue
- How well are forces being transitioned to and from battle formations?
- Are joint forces appropriately postured for operational formations?
- Are operations being directed at enemy centers of gravity?
- Are operations being conducted in depth?
- How effective are show of force and demonstration operations?
- How effective are forced entry operations?
- Are operations to seize, hold, and expand a lodgment effective?

Measure of Performance

How well are forces being transitioned to and from battle formations?
- ■ Time between changes of mission posture
- ■ Is force in contact or not at each time interval?

Are joint forces appropriately postured for operational formations?
- ■ Flexibility of available forces (How many different enemy forces are influenced by the presence or actions of a given friendly force?)
- ■ Is momentum being maintained (closure differential increasing) for attacking forces?
- ■ Is enemy momentum being disrupted (closure differential decreasing) for defending forces?

Are operations being directed at enemy centers of gravity?
- ■ Does any given enemy element have a significant number of friendly forces with positive/increasing closure differentials in relation to it?
- ■ Are enemy forces being attacked from unexpected directions?

Are operations being conducted in depth?
- ■ Are enemy forces being simultaneously engaged throughout the battlespace?

How effective are show of force and demonstration operations?
- ■ How many enemy force mission postures change due to friendly presence?

How effective are forced entry operations?
- ■ How rapidly does the density of forces change?
- ■ How rapidly does the closure differential change in areas of forced entry?

Are operations to seize, hold, and expand a lodgment effective?
- ■ What is the change in combat potential in the area of a forced entry with respect to time?

Data Requirements

For all units battalion and higher (or lower if operating independently):
- ■ Location
- ■ Intelligence (Current Knowledge situation)
- ■ Combat Power Orientation
- ■ Mission
- ■ Time since last mission posture change
- ■ In contact / not in contact
- ■ Current Supply tonnage

Figure 6. Dendritic for developing data requirements.

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The sub-issues in Figure 6 mirror the relationship between OP 1, Conduct Operational Movement and Maneuver, and the associated supporting tasks. This linkage is also similar to the structure of the Mission Training Plan developed by United States Atlantic Command for the training and evaluation of operational movement and maneuver planned by a JTF staff [Ref. 9: p. 5-IV-34]. It is useful to note that the overall recurring theme of all associated Measures of Performance involve the *spatial* and *temporal* relationship between enemy and friendly forces and the ability to *transition* the force.

B. MANEUVER CONCEPTS QUANTIFIED

In order to measure successful use of operational maneuver, some method of quantifying the first order effects of operational art must be determined. The key tradeoffs in operational art are forces, space, and time. The rates at which the three components interact as a function of the echelon is the key to understanding and representing operational art. [Ref. 10: p. 24] The interaction of forces, space, and time to determine the effects of operational maneuver conforms to certain simple laws of physics and thermodynamics. The application of military mass at a point on the battlefield with a certain velocity is a measure of the **momentum, ρ,** of the attack:

$$\rho = m \bullet v \qquad \text{(Eqn1)}$$

where, m = mass of the force: size and capability
          v = velocity of the force.

Similarly, military **force, F,** can be considered as the ability to apply that

same form of military mass at some rate of acceleration in the attack:

$$F = m \cdot a \qquad \text{(Eqn2)}.$$

Finally, the military **pressure, p,** exerted on an enemy force can be

defined as the ability to apply some level of force strength at a certain tempo,

over some defined area of influence in the battlespace [Ref. 11: p.76]:

$$p = \frac{nRT}{V} \qquad \text{(Eqn3)}$$

where, n = the number of forces affecting the enemy
R= a measure of the lethality of the force
T= the tempo or relative velocities in the operation
V= the volume of battlespace influenced.

In order to utilize these physical relationships the simulation model must

either contain parameters which liken to those described or it must produce data

from which those parameters can be derived. The resulting parameters are then

representative of the three components of operational art discussed at the

beginning of this section. These parameters describe the forces and the spatial

and temporal aspects of the battlefield.

Forces themselves are always modeled explicitly by parameters which

identify their capability. Strength, lethality and survivability are all accounted

for in detail because of their necessity in determining Lanchesterian attrition

outcomes. The space and time components, however, have no explicit representation and must be derived based upon constantly changing locations of forces on the battlefield over time. This representation must include more than simply using the speed of any given combat system, or aggregation of systems. Instead, it must be relational, taking into account the operational maneuver of both friendly and enemy forces, as well as the descriptive characteristics of the units over time.

C. DEVELOPMENT OF A RELATIONAL MEASURE OF PERFORMANCE

The need for a relational descriptive parameter leads to development of a measure of performance that is called the Fractional Closure Rate, or FCR:

$$FCR_{f,e}(t) = \frac{DISTANCE_{f,e}(t - \Delta t) - DISTANCE_{f,e}(t)}{MAX\left[DISTANCE_{f,e}(t - \Delta t), DISTANCE_{f,e}(t)\right]}, \forall f, e, t \quad (Eqn4)$$

where f = a specified friendly maneuver element or target
e = a specified enemy maneuver element or target
t = time of capture of the data.

The numerator of the FCR is a representation of the closure distance between two forces in some time interval, Δt, or more simply the approach velocity of two forces. It can be calculated during post processing by applying the Cartesian distance formula to position data collected at each force location change or a uniform time interval. Dividing by the maximum of the current or last distance between forces creates a measure which has the flexibility of demonstrating negative change in relation to the closure. In this form, withdrawing at a certain distance has a negative FCR of the same magnitude as

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an advance at the same distance. This is shown in the following example for a chosen enemy and friendly force indicated by indices 1,1.

$$DISTANCE_{1,1}(t - \Delta t) = 10km$$
$$DISTANCE_{1,1}(t) = 8km$$
$$\longrightarrow \quad FCR_{1,1}(t) = \frac{10 - 8}{10} = +0.2$$

And if the same two forces moved apart at the same distances,

$$DISTANCE_{1,1}(t - \Delta t) = 8km$$
$$DISTANCE_{1,1}(t) = 10km$$
$$\longrightarrow \quad FCR_{1,1}(t) = \frac{8 - 10}{10} = -0.2 .$$

The denominator also serves to normalize the contribution of great closure distances when further removed from an enemy threat. For example, upon arriving into theater, a force may cover 500 kilometers in 24 hours but still remain at a distance of 500 kilometers. The magnitude of this move is of no great value if the distance to the enemy is still significant. Therefore, a force which closes 50 kilometers and still has 50 kilometers between themselves and the enemy has the same calculated FCR within the same 24 hour period, despite the fact that this is a much shorter move. This normalization can be easily justified by the tactical nature of the latter forces approach and the planning time required.

Additionally, the derivative of the FCR can be written as spatial acceleration:

$$SA_{f,e}(t) = \frac{dFCR}{dt} = \lim_{\Delta t \to 0} \frac{FCR(t + \Delta t) - FCR(t)}{\Delta t}, \forall f, e, t \qquad (Eqn5).$$

The Fractional Closure Rate is developed only as a measure of *performance* to be incorporated into a measure of *effectiveness* for maneuver. It does have some stand-alone use as a measure of effectiveness of the ability of a force to maintain a high operational tempo. This translates to a quantitative measure of initiative and agility, using depth of attack as the data element. The closure of one friendly attacking force on one enemy defending force is demonstrated by the example in Figure 7. The illustration provides a graphical analysis of some of the implications of a change in the FCR and the spatial acceleration.

Time	Distance	FCR	ΔFCR
0	3	-	-
1	6	-0.5	0
2	10	-0.4	0.1
3	14.3	-0.3	0.1
4	17.75	-0.2	0.1
5	17.75	0	0.2
6	17.75	0	0
7	17.75	0	0
8	12.42	0.3	0.3
9	8.69	0.3	0
10	7.82	0.1	-0.2
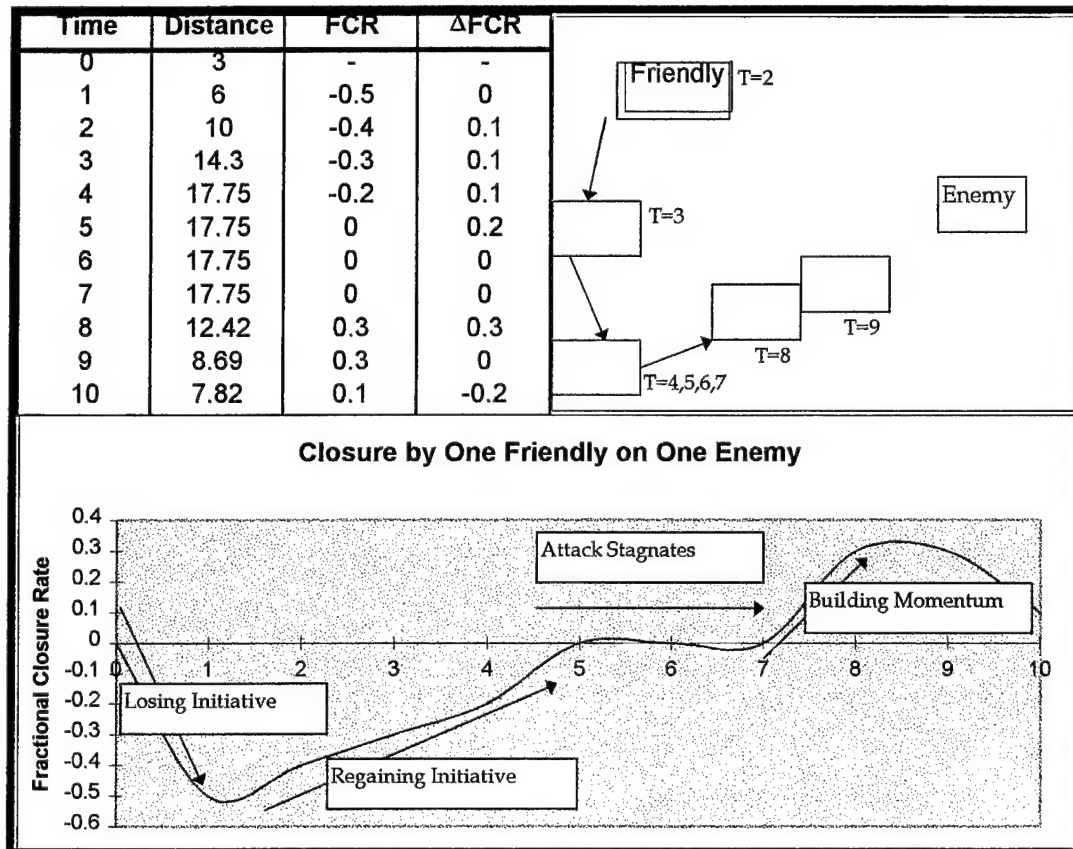
Figure 7. Fractional Closure Rate Behavior.

The illustration for the Fractional Closure Rate of one friendly force on one enemy force is instructional in that it identifies trends in the interaction between two forces. In light of the fact that the enemy has to be concerned with any force closing on him, an illustration of the FCR of many friendly forces versus one enemy is shown.

A simple linear combination of FCRs for all friendly forces may not be the most feasible representation of the overall pressure being applied to the enemy force. However, it does provide a view of the overall effects of more than one positive, or negative, closure rate with respect to a targeted force (Figure 8).

Time	F1	F2	F3	F4	F5	F6	TOTAL
0	0.00	0	0.00	0.00	0.00	0.00	0.00
1	0.91	-0.5	-0.51	-0.34	0.84	0.58	0.97
2	-0.98	-0.4	0.80	0.34	0.92	0.92	1.60
3	-0.16	-0.3	0.34	0.11	-0.13	-0.05	-0.20
4	0.97	-0.2	0.31	0.22	0.98	0.60	2.88
5	0.73	0	0.41	0.68	-0.04	0.88	2.67
6	-0.71	0	-0.25	-0.25	0.30	-0.81	-1.71
7	-0.28	0	-0.86	-0.88	0.75	-0.41	-1.70
8	-0.12	0.3	-0.56	-0.17	0.60	0.59	0.64
9	0.23	0.3	-0.55	-0.66	-0.08	-0.58	-1.34
10	-0.88	0.1	0.17	0.30	0.28	0.25	0.22
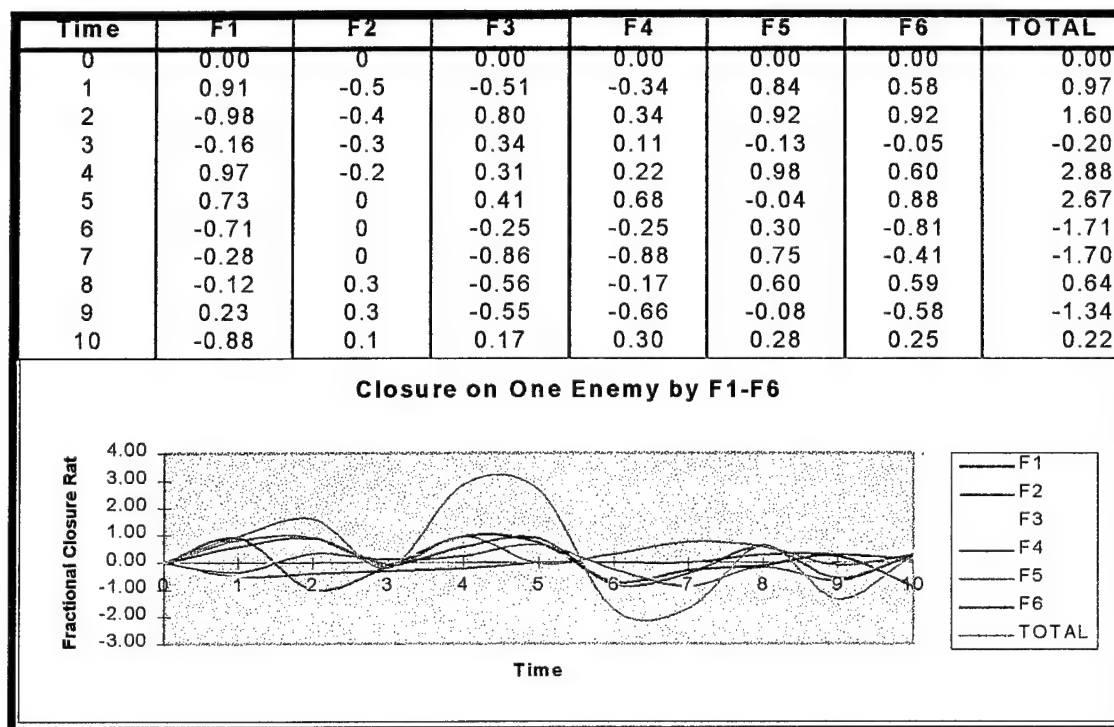
Figure 8. Aggregated Fractional Closure Rates on one Enemy Force.

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At this point it becomes apparent that the risk associated with any individual force FCR must be valued as being proportional to the relative worth or lethality of the force creating the closure. The most immediate questions to be answered when faced with an approaching enemy concern its capability (firepower), strength and time of arrival in the area of operations. The worth or value of a force in JTLS is part of the initial database in the form of a tactical unit prototype score, or TUP SCORE. Every unit is categorized with one of eighty-four prototypes, each having an associated TUP SCORE. This score can be developed using various techniques. For this effort the scores which exist within JTLS will be utilized. The scores can be found at Appendix A.

Additionally, the FCR is affected by a number of other factors, all of which were identified in the dendritic at Figure 6 as data requirements: supply rate, intelligence picture, mission posture, strength, and whether or not that force is or is not currently in contact. The intelligence and supply factors highlight the horizontal linkage in the UJTL, whereby a causal audit trail may, in fact, point to deficiencies in a separate functional area. Analysis here will focus on the posture and strength data to determine the true effect of a closure rate with respect to the force capability and mission.

To highlight these effects consider two friendly forces, A and B, with identical FCRs in relation to one enemy force. One force, A, has recent intelligence of the enemy situation while the other is moving blindly and

battling light resistance. Additionally, force A has been recently resupplied and is at 90 percent strength, while the force B is at 70 percent and awaiting replenishment of ammunition. If each of these units was exhibiting the same closure behavior on an enemy force, the worth of the force would be degraded by its weakened, uninformed, and poorly supplied status. This in turn should degrade the Force B FCR relative to the FCR for Force A. Therefore, this measure of performance must be weighted accordingly.

D. DETERMINATION OF FIREPOWER SCORE

Each unit in JTLS is represented by various parameters in the database. These numbers are defined before execution of the game and are used throughout to determine the outcomes of unit actions from resupply to combat. One of the more widely accepted methods for determining the value of a force in relation to its capabilities as a member of the entire force is the Eigenvalue, or Anti Potential -Potential Technique. One system type is selected as the baseline and all other force values are determined mathematically as scaled values of the baseline. Each weapon type is valued based upon its ability to attrit each of the possible enemy systems it could face. This is a much more technical method of assigning force lethality indices than JTLS requires to properly simulate aggregated combat.

Within the JTLS database these scores, determined by a less rigorous judgmental method, are stored within Tactical Unit Prototypes as Combat

System Scores (TUP CS SCORE). The scores are then used in calculating the overall value of a unit by multiplying the TUP CS SCORE by the number of units of that type. These aggregated scores will be used to represent the overall mass of the forces when determining the effects of closure.

E. WEIGHTING THE FCR AND ITS RELATIONSHIP TO BATTLEFIELD PHYSICS

Utilizing the FCR as a measure of velocity, the physical analogs of the battlefield can be rewritten in terms of this *relational* and *spatial* velocity and acceleration to provide the physical measures for evaluating operational maneuver. The TUP CS SCORE will be used to weight the FCR, thereby taking into account the strength and worth of a force:

$$m_f = \sum_i TUP\ CS\ SCORE_i * \#SYSTEMS_i * \%\ STRENGTH$$

where i represents each weapon system type (Eqn6),

and the measure of effectiveness is:

$$\langle MOE \rangle = m_f \cdot FCR_{f,e,t} \tag{Eqn7}.$$

The FCR can be considered a form of the derivative of the position vector, or a velocity. By substitution into Equation 1, an MOE which assesses the Military Momentum directed against an enemy force over time is:

$$\rho_e = \sum_f m_f \cdot FCR_{f,e,t}, \forall\ t \tag{Eqn8}.$$

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Similarly, the spatial acceleration can be substituted into Equation 2, or take the derivative of Equation 6, and the resulting MOE is Military Force directed against an enemy at any time:

$$F_e = \sum_f m_f \cdot \frac{dFCR_{f,e,t}}{dt}, \forall t \qquad \text{(Eqn9)}.$$

Finally, the pressure exerted on an enemy force at a given time by any number of friendly forces can be obtained by:

$$p_e(t) = \frac{n \sum_{\forall f} m_f \cdot FCR_{f,e}(t)}{AI_e} \qquad \text{(Eqn10)},$$

where,

n = the number of forces with an area of influence affecting the enemy and,

AI = the doctrinal area of influence of enemy force, e (km^2).

In order to accurately assess the MOE from Equation 7, a set of rules must be applied to decrement or screen out the use of an irrelevant FCR. In situations where the available intelligence or capability of the closing force is less than ideal, the MOE must be weighted accordingly. For the purposes of analyzing maneuver alone, the assumption of perfect intelligence will be made. Also, only the effects of weighting the FCR by strength and TUP score will be investigated to portray the MOE from Equation 7. This will be accomplished through the use of screening criteria within a spreadsheet and Pascal formulations discussed in

the next chapter. The physical analogs in Equations 8, 9 and 10 are offered for consideration and simply expand on the notion of a weighted FCR.

F. SPREADSHEET AND TURBO PASCAL DATA ANALYSIS

Rolands and Associates, the developer of JTLS, has created a number of routines which continually update ASCII output files with critical data during the conduct of a JTLS exercise. These files have been developed in conjunction with the UJTL assessment effort and provide a variety of data describing engagement results, resupply, and a number of other characteristics. The data are chronological and serve to assist in the identification of changes in the behavior of the data during critical events. Three post processor files were used in support of assessing maneuver. The location, posture, and strength files were all utilized in spreadsheet and Turbo Pascal® implementations to assess the MOEs developed. Examples of the input files are in Appendix B. The files were read into an Excel® spreadsheet and sorted by (1) Force Name and, (2) Time. This allowed for simpler development of the input procedures in the Pascal code. The Pascal program was written in order to create a Node-Arc representation of all the chronological data. A graph using an adjacency list was developed using the linked list structure shown in Figure 9. The graph stores all pertinent time, posture, strength, and location data. This allows for easy accessibility and analysis of any force at any time and its relationship to all other units on the battlefield. The computer code is given in Appendix C.
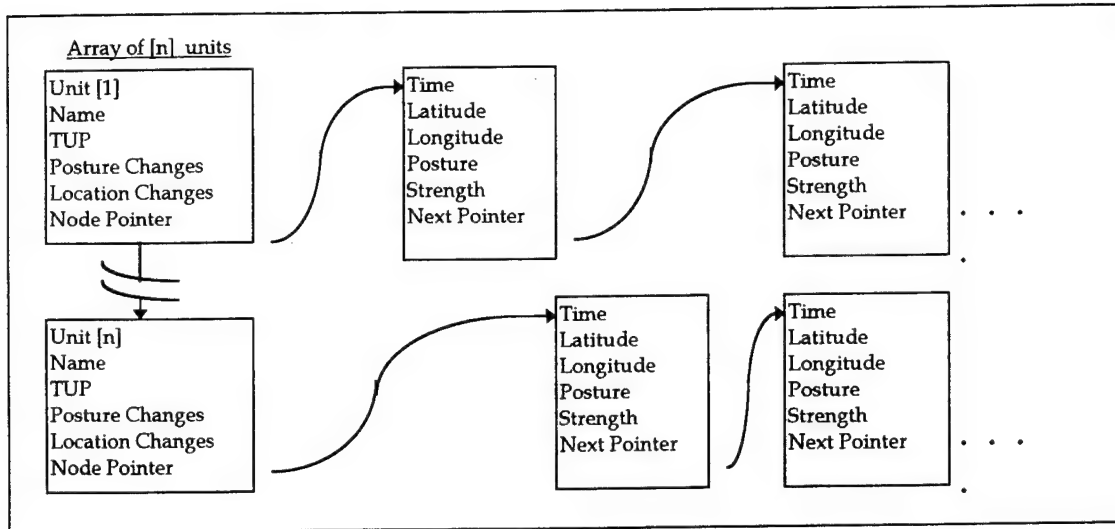
Figure 9. Node-Adjacency List Representation of Data.

The Pascal program first reads in the location, posture and strength of every force at any given time to create the graph. The user then identifies a force of interest for which to calculate Fractional Closure Rates from Equation 4. The code accesses a procedure (based upon the Great Circle Distance routine used by JTLS) to determine the distance to all forces from any chosen force over the entire run time of the game. Generation of closure calculations with respect to a specific force creates a dense graph which connects the location of that force to all others on the battlefield over the entire run time of the simulation. The Pascal code for closure calculation has an order of complexity, $O(nm)$, of (Number of Units) X (Number of Moves by all Units). An input file of approximately 1 megabyte generated nearly 10 megabytes of output in the controlled experiment containing 200 units.

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The resulting outputs provide a listing of the distances, closure rates, and spatial accelerations for that force in relation to all others from start to finish. Additionally, the node adjacency list is output to a file which can be inspected to determine any force location at any time and their strength and posture. A sample of the adjacency list can be found at Appendix D. This program greatly simplifies the calculations and allows for assessment of any combination of forces closing on one force over time. The output files are then opened in Excel to produce graphical representations similar to the one demonstrated in Section C of this chapter. By multiplying the value of the TUP by the strength, and then by the closure or spatial acceleration, the appropriate MOE from Equation 7 can be analyzed. The proposed physical analogs could be investigated as well.

Listing the posture in the output file allows further assessment with respect to critical events and the impacts of force posture on the rate of closure between forces. The results obtained from the experimental runs and this technique will be discussed in the next chapter.

IV. EXPERIMENTAL SIMULATIONS

A. MANEUVER REPRESENTATION IN JTLS

The Joint Theater Level Simulation uses SIMSCRIPT to support the need for a discrete time simulation. The advantage of the discrete time simulation is the ability to model activities that have been identified as critical events. The key processes of theater level, air land battle are most easily visualized as a collection of discrete (key) events. These critical events (a) take time to occur and (b) potentially change the state of the systems. [Ref. 6, 2.9-2.10] It is these characteristics that are of interest in gathering the appropriate data for the assessment of operational maneuver.

The ground functions which are explicitly modeled are numerous but can be generally categorized as shown in Figure 10.

Attrition	Movement & Maneuver	Mobility/Countermobility /Survivability	C²
Direct Fire	Movement	Delay/Attrition from	Force Organization
Indirect Fire	Attack	mines	Command
	Defense	Nuclear/Chemical attrition	Control
	Delay	Military Engineering	Communication
	Withdrawal	Mine Emplacement	
		Destruction by demolition	

Figure 10. Ground Functions Modeled in JTLS.

These functions are executed by units which are modeled as entities within the simulation. Each unit is modeled by the previously discussed Unit Prototypes. These prototypes identify the equipment, capabilities, and supply requirements of a unit. The unit can be ordered into various postures and missions listed under movement and maneuver in Figure 10. Additionally, the unit will change postures if pre-established attrition thresholds are reached.

Movement itself is determined by Dijkstra minimum time and distance algorithms based upon destinations input by the player. [Ref. 6] Factors affecting the movement include the terrain representation and the unit characteristics. The characteristics are further affected by such factors as strength, supply rate, maintenance, and ground combat. These causal relations aid in validating the use of the Fractional Closure Rate methodology. The closure rate is dependent on factors which occur as a result of other functional areas, again highlighting the horizontal linkage of the UJTL. Additionally, the FCR is an end result of command and control decisions and player perception. These characteristics differ from the functional area characteristics in that they are not explicitly modeled. Analysis of output data trends could provide valuable insight as to the psychological impacts on strategy and decision making in conducting maneuver warfare with a closing enemy.

B. SCENARIO REQUIREMENTS

The scenarios were all set in the Southwest Asia theater of operations. The standard scenario allowed for the buildup of American forces in the region before any Iraqi incursion, typical of recent history. The variations were developed to demonstrate changes in maneuver results and to establish conditions for successful development of the measures of performance identified in Figure 6. A number of configurations were developed for the experimental runs of JTLS. These combinations are shown in Figure 11. Two different starting scenarios were investigated. One provided for conditions which represented sufficient time for force build up (Light). A variation exhibited conditions of an enemy seizure of the strategic initiative, sufficiently degrading the ability to build combat power quickly in theater (Heavy). The second scenario resulted in long distances being covered to bring forces in contact with the enemy. This provided for analysis of the ability or inability to create a temporal advantage in less than ideal conditions.

Within each of the different starting scenarios, a run was conducted for situations where each side gained the *operational* advantage with respect to initiative. Certain key decisions were scripted to insure that one side or the other was able to exploit an advantage to demonstrate the effect on the FCR and its related measures of effectiveness.

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	Heavy Scenario Initial Iraqi Incursion	Light Scenario Iraq Postured on Border
Iraqi Initiative	Run #1	Run #3
American Initiative	Run #2	Run #4

Figure 11. Experimental Run Conditions

C. THE HEAVY SCENARIO

The heavy scenario was established to demonstrate the difficulty in generating combat power and establishing a temporal advantage. It is assumed the situation could occur for any number of reasons. These reasons could relate to the occupation of American assets in another region or the ability of an aggressor nation to recognize the need to seize the initiative in the overall strategic situation. The Iraqi forces in this scenario have attacked across the border to Hafir-al -Batin in north central Saudi Arabia and to the Kuwaiti border along the coast. The immediate objective was to seize the Trans-Arab pipeline and control the flow of oil in northern Saudi Arabia. Force locations as American forces begin to arrive in theater are shown in Figure 12.

The deployment sequence was formulated to allow for one brigade each from the 101st Airborne Division and 24th Mechanized Infantry Division to arrive without difficulty at a port city near the city of Dhahran. Because the database already contained United Kingdom forces in the region, they were used to

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support Saudi Arabian forces in the vicinity of King Khalid Military City (KKMC). Finally, the Iraqi advance along the coast stopped short of crossing into Saudi Arabia, allowing the deployment of two Marine Expeditionary Units into the area of Al-Khafji. Under the conditions of Iraqi *strategic* initiative, forces attacked well in advance of any Allied presence in the region. This assisted in capturing data relevant to analysis of operational level task OP 1.2.3, Concentrate Forces in Theater of Operations, and set the stage for the conduct of operational maneuver. Given these conditions, a run was conducted demonstrating seizure of the *operational* initiative by each force side.

Figure 12. Heavy Scenario Initial Force Dispositions.

1. Iraqi Initiative

For the purposes of analysis, the Iraqi forces secure the operational initiative by conducting preemptive air strikes on deploying United States forces. Forces from the 2nd Brigade of the 24th Mechanized Infantry Division (2/24th Mech) are given the mission to move west and support the defense of KKMC. The Iraqi air and ground efforts are designed to impede that movement.

The progress of this movement is exhibited in Figure 13, with curve behavior pointing to causal events which impede or facilitate that progress. The actual data, shown by the yellow curve, exhibit a somewhat chaotic nature due to the discrete state changes and the causal effects of critical events. While the critical events are of interest, the erratic behavior overall distracts from the trend being demonstrated. Smoothed estimations do not represent the main effects being investigated since it is the discrete, extreme changes which help in identifying key issues for establishing causal audit trails. Therefore, the trendline, shown in black, utilizes every three data points to calculate a moving average. The trendline is a more characteristic representation of the overall trends in initiative and momentum. The actual data are also plotted in order to clearly identify causal events.

A slow, but successful movement toward the objective area is demonstrated by the gradual rise in the FCR from first movement at approximately 0.5 decimal days in Figure 13. Movement is interdicted at 0.625 decimal days into the battle by Iraqi aircraft and delayed. Damage is simulated

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and the resulting time of repair induces further delays. This, in turn, produces a drop in momentum until the completion of the first day. Additionally, the initiation of the ground offensive by the Madinah Division creates movement away from the 2/24 (M) static location, further decreasing the closure. As the damage is repaired the closure ratio begins to increase rapidly for about 0.25 decimal days, or six hours. During this time the 2/24 (M) is able to close on KKMC and the Madinah Division, and join the battle. The more pronounced spatial acceleration, or slope of the FCR, is the result of the relational movement of the two forces moving toward the same location at this point in the battle. The Madinah movement was necessary to initiate ground combat with forces already at KKMC, thereby maintaining the operational initiative.

As the Madinah Division begins to withdraw from contact at 1.15 days, the FCR initially drops off before stabilizing back to the gradual rise exhibited in the first few hours of the scenario. At this point in the battle the Madinah begins to lose its momentum, and the unimpeded 2/24 (M) closes and joins battle at approximately 1.5 days. For the next twelve hours, or 0.5 days, the American force is able to create a favorable tempo, but has arrived well after the Iraqi force was able to withdraw. Though creating a favorable FCR from 1.5 to 2.0 days, it is occurring at the expense of pursuing an enemy with whom they still have not gained contact. Finally, at the beginning of the second day, the Madinah Division continues its withdrawal uninhibited by American efforts. The curve characteristics at this point are useful to a CINC in evaluating the exercise. The defeated Iraqi force is able to reduce the FCR. This translates to an inability to

prevent a force from escaping the battle area. If this was intentional, then the curve is simply an affirmation that the plan was properly conducted. If not, this analysis portrays the inability of the 24th Mech to maintain the tempo and create a favorable FCR with respect to the Iraqi forces.
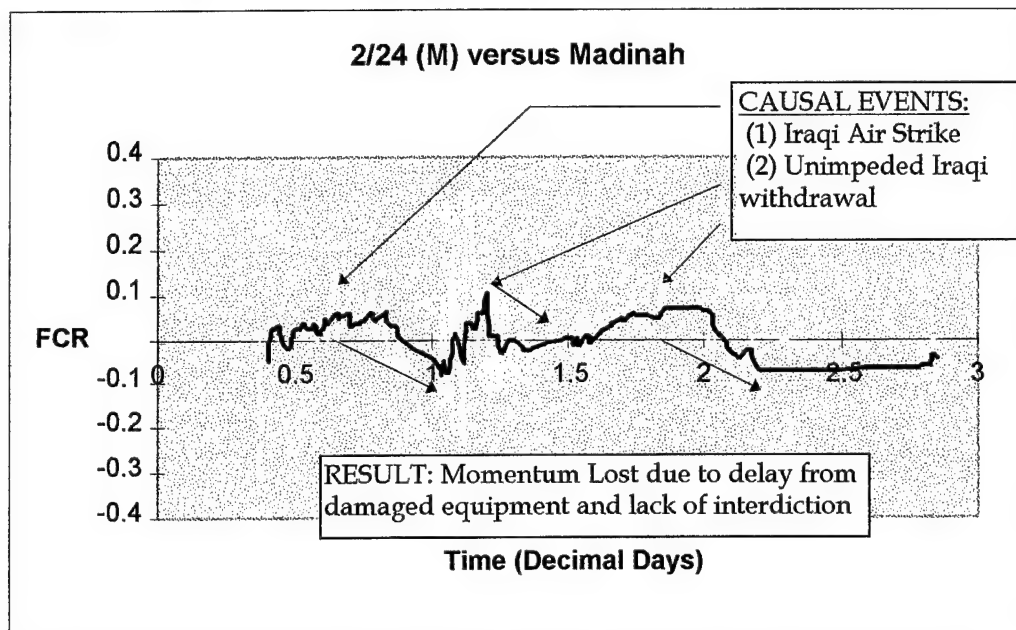
Figure 13. Effects of Interdiction on Closure.

The Madinah Division executes the withdrawal along with the Hammurabi Division. The movement is from the KKMC area of operations to support forces along the coast. Given the lateral movement of the Iraqi forces, a successful counterattack plan would slow the withdrawal. This would prevent employment of these divisions elsewhere in theater (OP 1.1.2 Conduct Intratheater Redeployment and OP 1.2.3 Concentrate Forces in Theater). The graph in Figure 14 demonstrates that, despite a withdrawal posture, the Iraqi forces maintain a maneuver advantage.

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1st Armor (UK) in pursuit of Madinah
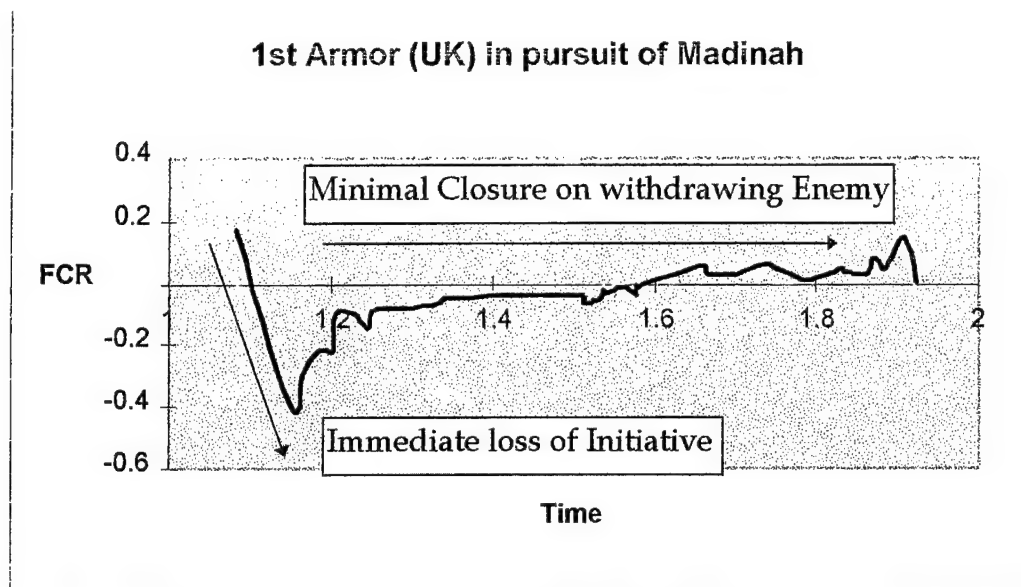
Figure 14. **Loss of Initiative in Battle Transition.**

The zero slope nature of the graph from 1.2 days to 1.6 days translates to a 10 hour period of time during the Iraqi withdrawal during which the Allied force did not maintain an aggressive pursuit. This type of information is valuable in conducting post exercise analysis. Perhaps a force that was allowed to escape in this manner reconstitutes and causes great damage later within the theater. This was the intent of the controlled experiment; however, the modeled Iraqi units were not capable of producing significant results against the forces fighting along the coast. The Iraqi forces were still soundly defeated despite the time for rearming and refitting granted by the lack of Allied pursuit. This highlights one of the underlying themes of this thesis. Battlefield results cannot be determined only by the initial attrition capability assessments. There is a lack of flexibility in attrition assessment for an enemy force that, while not well equipped, has gained the upper hand in the conduct of battle. This prohibits the effects of maneuver from affecting overall outcomes.

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2. American Initiative

Using the same starting scenario as shown in Figure 12 and described in the previous section, the simulation was re-scripted to include Allied command and control decisions which demonstrated seizure of the operational initiative. Despite the initial posture of Iraqi forces, this scenario allows American forces to arrive in theater without interruption and fully deploy to defensive positions by the close of day one of game time. Additionally, a lack of Iraqi offensive activity allows for American air and ground attacks to initiate action against defending Iraqi forces. The analysis which follows highlights the critical changes in curve behavior based upon different command and control decisions.

The American plan was to advance the 2nd Brigade of the 24th (M) to the same location in an attempt to build Allied combat power in that area. The discussion of their successes and failures is identical to that of the Iraqi reserve. Figure 15 demonstrates the FCR between each of these operational reserves for each run as they approached the main battle area near KKMC.

The 17th Iraqi Armor Division was deep in Iraq in both runs of this scenario. In each run the 17th advanced along the same route in an attempt to join the battle near KKMC. Figure 15 demonstrates that when Iraq maintained the operational initiative, the 17th Armor exhibited a positive closure rate on the main battle area. The division exercised freedom of maneuver throughout the run. The FCR was consistently positive and generally increasing. During periods where the withdrawal posture was assumed, the FCR, while negative,

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exhibited a negative acceleration. This was indicative of a compounding Allied loss of momentum. In the second run, however, Allied air attacks and successful, uninterrupted movement of American brigades caused a flattening of the Iraqi 17th FCR. This demonstrates the Iraqi inability to regain any momentum after the critical causal event of an airstrike.
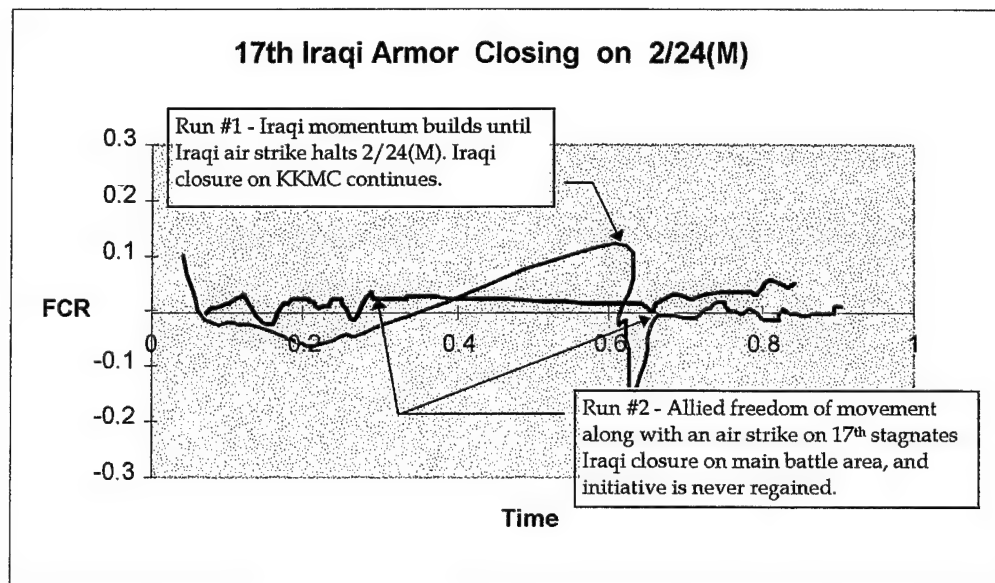
Figure 15. Comparison of Operational Reserve Closures.

The ability of the Allied air attacks to disrupt Iraqi attempts at regaining the initiative and accelerating the attack is demonstrated graphically in Figure 16. The period from 0.6 to 1.2 decimal days is expanded from Figure 15. Each time the value for the spatial acceleration began to increase, an Allied air strike caused an immediate reduction in SA(t) and a period of recovery during which Allied closure on KKMC was uninterrupted. The screen shot at Figure 17 shows

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the Allied air attack and the 2/24 (M) movement in order to visualize the scenario. Examples of the data generated for this analysis are in Appendix E.

17th Iraqi Armored Division

Following the two airstrikes, momentum drops and the acceleration of the attack is affected for more than 6 hours

SA

— SA(t)

Time
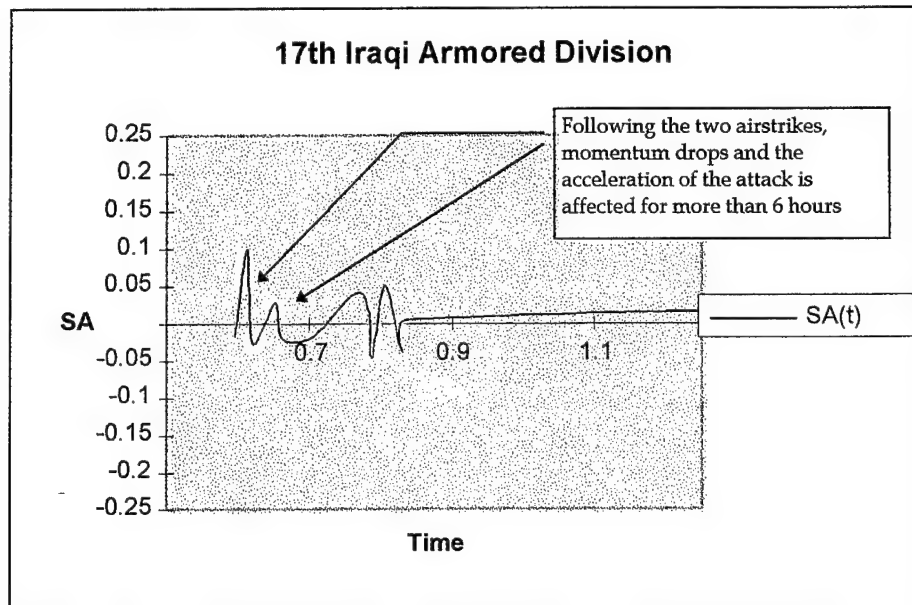
Figure 16. Spatial Acceleration affected by Allied Air Strikes.

17AR-280000
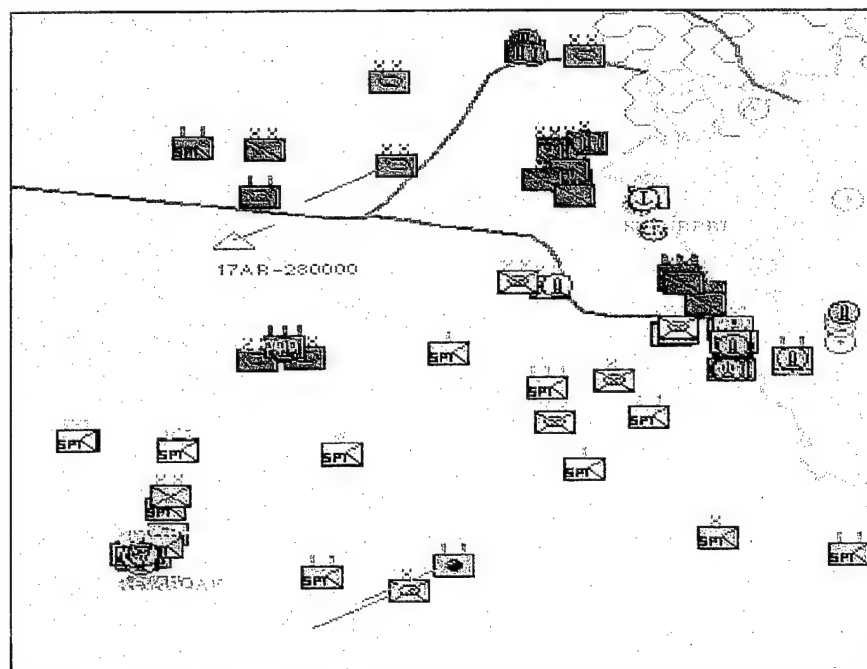
Figure 17. Allied Air Strike on 17th Division

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D. SUMMARY

The Operational Maneuver analysis identifies that the 2/24th Mechanized Infantry Brigade had difficulty maintaining the initiative and establishing momentum. The identification of the causal, critical events found the enemy air strike and the inability to slow the Iraqi force to be the prime contributors. It is at this stage of analysis that the vertical linkage of tasks and the synthesis of all theses assessing the UJTL becomes critical.

The need to identify the critical events and then establish a causal audit trail throughout all functional areas prompts further discussion of the results shown in Section C. A functional area analysis of Figure 13 would lead to further causal discussions with respect to OP 6, Provide Operational Protection , OP 3, Employ Operational Firepower and OP 5, Employ Operational Command and Control. Knowing that the Operational Maneuver was affected is not sufficient. To be useful to a Unified Commander-in-Chief these results must point to the "why's" of these effects.

Were there sufficient Air Defense assets with the moving force (OP 6.1.4 Counter Enemy Air Attack in Theater of Operations)? Was Operational Firepower available to interdict the Iraqi withdrawal (OP 3.2.5.1 Conduct Air Interdiction of Operational Forces) ? Did the staff properly plan for follow-on operations (OP 5.4.4 Synchronize/Integrate Operations)? The language for each of these vertically linked tasks contains reference to many of the issues which have been quantitatively captured or discussed here. The decisive point, combat

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potential, centers of gravity, momentum and the enemy commander's decision cycle are all addressed in the Universal Joint Task List Manual. By capturing the conduct of Operational Maneuver, the task of identifying a causal audit trail has a well grounded start point.

V. RESULTS AND CONCLUSIONS

A. MOVEMENT VERSUS MANEUVER

It is critical to note how the measures introduced are intended to be utilized. The subject under consideration is operational *maneuver*, and it may seem that there is nothing valuable, or even comparable about *movement*. But consider that while the operational commander has the force generation concern of introducing forces in theater, the operational commander does not have the same luxury. He must efficiently and aggressively employ the forces he has on hand in many directions at many different times. Effective force generation depends upon how well he can articulate his needs and how good his decision cycle is so that he does not have forces moving in an untimely way to a place where they are not needed. [Ref. 12]

The curves shown in Chapter IV are only worth analyzing if we are looking at a force that was purposely moving toward, or away, from critical nodes on the battlefield. The methodology introduced here allows for those nodes to be identified as targets or forces and could be employed to help assess closure on the overall center of gravity if identifiable.

B. FUTURE WORK

The methodology relies on the understanding that one cannot isolate the effects of only one enemy force against one friendly force on a dynamic, non-linear battlefield. Despite the ability of the Pascal implementation to generate

the necessary data for the many interactions, further work should be done to automate the graphical displays for after action review use. Within the massive output files many forces may have exhibited interesting closure rates that were overlooked.

A Master's Thesis entitled *Direct Fire Synchronization* utilizes spatio-temporal displays and describes their impact on the cognitive processes of an audience [Ref 14]. The data generated in this thesis would benefit from a similar display which could show potential "hot spots" of force closure. This expansion could facilitate the further exploration of the physical analogies introduced in Chapter III.

C. THE SPECTRUM OF CONFLICT

The measures developed have application throughout the spectrum of conflict from peace keeping operations to a major regional conflict. Consider the purpose of disaster relief operations or noncombatant operations: gain control of the situation by placing the proper assets in the proper place as quickly as possible. The FCR method can identify if initiative is being maintained in those operations as well as combat. The use of the FCR as a measure in those instances could assist in refining decision making and resource allocation to insure coverage of the most critical problems and rapid closure on completion of the tasks at hand.

The relationships in the use of the FCR do not need to be bound to friendly versus enemy. Though not demonstrated here, the measure could also

point to command and control problems, logistical separation given a certain mission posture, and the level of mutual support, or lack thereof, in the attack.

D. REVOLUTION IN MILITARY AFFAIRS AND SIMULATION RESULTS

The FCR has been described as demonstrating critical doctrinal concepts such as agility and initiative. If the services believe in the mechanics which underlie these concepts and battlefield effects, then perhaps simulations should insure that the tempo of battle somehow degrades the attrition capability of those who do not control it. In his foreword to the Richard Simpkin book, *Race to the Swift*, General (Retired) Donn Starry answers his own rhetorical question, "What does win?" by stating that in battles where force ratios were within understood "standoff" limits, the majority of winners were those who seized the initiative from the enemy and held it to battle's end. He goes on to state that "Most often the initiative was successfully seized and held by maneuver". [Ref. 13: p. 112]

As the information age and technology seem to run off into the future we must not forget that it cannot leave its forces behind. Time is the new dimension in warfare and, though smart bombs and long range strike will help defeat that gap, our armed forces will always need to maintain the capability to take ground. Information is outpacing the capability of the forces receiving it. The revolution in military affairs, while in many ways suspended in the stars via satellites, is only as good as the user on the ground and how well he uses it. Perhaps the FCR can be a measure of effectiveness of information, command and

control, and maneuver all in one. To quote FM 100-5, *Operations*, "the ultimate measure of command and control effectiveness is whether the force functions more effectively and more quickly than the enemy [Ref. 13: p. 128]."

APPENDIX A. TUP SCORES USED IN JTLS

The data in the following spreadsheet are taken from the On Line Players Manual in JTLS. The number represents the overall firepower score for a unit using any of the 84 prototypes. This score is not used in determining battle outcome, but does impact on the capabilities and resupply of a unit. These scores are the values discussed in the development of military mass, m_f , and are aggregated for all systems in the identified unit.

TUP #		PROTOTYPE		SCORE
1		MECHBN.2		2790
2		SFBN		235
3		BNHQ		184
4		MECHBN.3		2874
5		INFBN.1		2040
6		INFBN.3		1557
7		ARBN.1		6230
8		ARBN.2		2208
9		ARMCAVSQ.2		1757
10		FABNSP.1		3987
11		FABNSP.2		4054
12		ADAINF.1		754
13		DISCOM.IN		1748
14		STCO.1		543
15		HHAVNBN.1		6134
16		HHAVNBN.2		840
17		UHAVNBN.1		5379
18		UHAVNBN.2		840
19		AHAVNBN.1		4430
20		AHAVNBN.2		1040
21		NAVAIR.1		1330
22		MARAIR.1		1540
23		AFAIR.1		2833
24		AIRLIFT.1		2033
25		BOMTRAN.1		1233
26		AIRRGT.2		6146
27		ENGINF.1		1283
28		FARP.1		322
29		DIVHQ.1		384
30		INDIVHQ.1		468
31		MXDIVHQ.1		868
32		ARDIVHQ.1		1168
33		ABNDIVHQ.1		468
34		ASLTDVHQ.1		468
35		ABNBDEHQ.1		207
36		ASLTBDHQ.1		207
37		ARBDEHQ.1		207
38		MXBDEHQ.1		207
39		INFBDEHQ.1		207
40		MRR.2		10434
41		MRD.2		48673
42		TANKRGT.2		9355
43		TANKDIV.2		45607
44		CIVSMALL.1		3120
45		CIVIL.AFFAIR		155
46		CIVLG.1		30510
47		SF.ODA.1		275
48		SCUD.BATTERY		120
49		RECON.TM.3		192
50		TANKBN.3		3601
51		INFRGT.3		2696
52		MXRGT.3		3380
53		FARGT.3		4185
54		TANKRGT.3		5194
55		MLRS.1		3525
56		SF.GP.1		370
57		AIRBASE.1		880
58		IQINFDIVARTY		4185
59		FABNTWD.1		1593
60		AIRCAVSQ.1		6075

APPENDIX B. SAMPLE INPUT FILES FROM POSTPROCESSOR

This information is representative of the input files received from Rolands and Associates. The files were prepared for Pascal by opening them in a spreadsheet and removing excess columns and characters. A sample from each of the location, posture, and strength files is included. The input files ranged in size between 3000 to 48000 bytes.

Posture File, Heavy Run, Blue Initiative:

Game Time	Side	Unit	Posture	Mission
0.566758	1	D-3-7IN24	INACTIVE	INACTIVE
0.584028	1	17ARDIV	MOVING	DEFEND
0.584028	1	17ARDIV	MOVING	MOVING
0.625694	1	101DISCOM	MOVING	DEFEND
0.625694	1	101DISCOM	MOVING	MOVING
0.625694	1	2BDE24MX	MOVING	DEFEND
0.625694	1	2BDE24MX	MOVING	MOVING
0.626383	1	389FS	AIR_OPNS	DEFEND
0.626383	1	48FW	AIR_OPNS	DEFEND
0.645774	1	1FW	AIR_OPNS	DEFEND
0.645774	1	27FS	AIR_OPNS	DEFEND
0.654172	1	1-41FABN	MOVING	MOVING

Location File:

Game Time	Unit Type	Unit	Latitude	Longitude	Force Side
2.635056	2	VII-300004	30.84368	46.2272	0
2.635812	2	VII-300004	30.91667	46.16667	0
1.5	1	VIICORPS	27.49725	48.51149	1
1.5	1	VIIFA	27.48891	48.5088	1
1.8	1	XVIIIABC	27.41667	48.26667	1
2	1	XVIIIFA	26.39403	50.05986	1
2.5592	3	ZSU-13	29.98023	47.34838	0
2.5592	3	ZSU-13	29.98023	47.34838	0
2.576049	3	ZSU-13	29.87511	47.30228	0
2.576049	3	ZSU-13	29.87511	47.30228	0
2.583366	3	ZSU-13	29.7712	47.30788	0
2.583366	3	ZSU-13	29.7712	47.30788	0
2.600228	3	ZSU-13	29.72952	47.43303	0

Strength File:

Game Time	Unit Type	Unit	Strength
0.001	1	JFCMD.KU	99.43
0.001	1	KAHUINBDE	99.89
0.041667	1	KHARG.BTY	99.88
0.041667	1	KU.FORCES	99.83
0.041667	1	MADINAH	99.47
2.791689	1	MADINAH	95.13
2.833356	1	MADINAH	94.23
2.875023	1	MADINAH	83.46
2.91669	1	MADINAH	61.29
3	1	MADINAH	50.32
3.000024	1	MADINAH	39.68

APPENDIX C. TURBO PASCAL CODE USED TO LINK DATA AND CALCULATE CLOSURE

Documentation is in the comments within the code. The executable file is not created to catch user errors. The Great Circle Distance used in JTLS was used to determine the conversion factors included here. The code does not execute calculation of the MOE, only the Fractional Closure Rate and Spatial Acceleration. Further improvement could include the linking of TUP scores within the code and calculation of the measures identified in Equations 7, 8 and 9. Even further improvement could include the use of a graphical overlay which visually depicts the magnitudes of those measures using varying color intensities on a screen shot from JTLS.

```pascal
program closuremaker;

{*******************************************************************}
{                                                                   }
{  Author - CPT Kevin Brown                                         }
{        July 1996                                                  }
{                                                                   }
{     This main program calls grunit to execute a variety          }
{  purposes. Refer to the unit and thesis 'Evaluating Operational   }
{  Maneuver in a Computer Aided Exercise'.                          }
{     The loops here in the main program allow for the creation     }
{  of data analysis for any number of JTLS runs,   and any number   }
{  of forces within each of the runs.                               }
{*******************************************************************}

uses wincrt,grunit;

var g               : GraphType;
    query1,query2   : char;


begin
 query1:='y';
 while query1<>'n' do begin

   query2:='y';
   Location(g);
   Posture(g);
   Strength(g);
   MovesList(g);
   while query2<>'n' do begin
    closurecalc(g);
    writeln('Another Unit?');
    readln(query2);
   end;
   writeln('Another Battle?');
   readln(query1);
 end;
end.
```

unit grunit;

```
{*************************************************************}
{  Author - CPT Kevin Brown                                  }
{        July 1996                                           }
{                                                            }
{   This unit contains procedures used to consolidate data placed }
{ in postprocessor files during a run of JTLS.  A linked list is  }
{ created which allows for the user to analyze a variety of state }
{ changes associated with:                                   }
{               (1) LOCATION     (2) POSTURE                 }
{               (3) STRENGTH     (4) CLOSURE                 }
{   The retrievable output consists of adjacency lists which are  }
{ indexed by unit and linked by time, and force relationship data }
{ which are described in the thesis 'Evaluating Operational  }
{ in a Computer Aided Exercise'.                             }
{                                                            }
{*************************************************************}
interface
const MAXUnitSIZE=250;
type NodePOINT  = ^AdjType;
     AdjType    = record
                  Time      : real;
                  Lat       : real;
                  Long      : real;
                  Posture   : string[8];
                  Strength  : real;
                  NextMove      : NodePOINT;
             end;
     UnitName   = record
                  Name      : string[9];
                  TUPScore     : real;
                  PostureChanges : integer;
                  NumMoves     : integer;
                  FirstMove    : NodePOINT;
             end;

   arrayTYPE    = array [1..MAXUnitSIZE] of UnitName;

   GraphType = record
             NumberofUnits: integer;
             UnitNum  : arrayTYPE;
           end;

procedure Location(var g: GraphType);
procedure Posture( var g: GraphType);
procedure Strength (var g: GraphType);
procedure MovesList ( var g: GraphType);
```

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```pascal
procedure closurecalc (var g: GraphType);
implementation
{*****************************************************************}
{  Receives data from sterilized pplocation file.  Modified file must have        }
{  all extraneous columns removed; only Time,Lat,Long,Unit Name remain and   }
{  in that order. Also must be sorted by Unit Name.                                    }
{*****************************************************************}
procedure Location(var g: GraphType);
 var j                          : integer;
    sTime,sLat,sLong,Last    : real;
   sName,Flag               : string[9];
   Current                  : NodePOINT;
   filename                 : string;
   Infile                   : text;
begin
   j:=0;
   Flag:='NONE         ';
   Last:=9999;
   writeln('Input filename for location data  (MUST be pre-sorted)');
   readln(filename);
   assign(Infile,filename);
   reset(Infile);
   writeln('Reading File....');

   with g do begin
     NumberofUnits:=0;
     while not SeekEof(InFile) do begin
       readln(InFile,sTime,sLat,sLong,sName);
       if sTime<>Last then begin        {Do not rewrite same info}
         if (sName<>Flag) then begin    {Start new indexed units list}
            j:=j+1;
            UnitNum[j].Name:=sName;
            UnitNum[j].NumMoves:=0;
            UnitNum[j].PostureChanges:=0;
            {AssignTUP(UnitNum[j].Name;} {<---Not used in this
                                               implementation}
            new(UnitNum[j].FirstMove);
            Current:=UnitNum[j].FirstMove;
            Flag:=sName;
         end
         else begin             {Continue adding to old units list}
            new(Current^.NextMove);
            Current:=Current^.NextMove;
         end;   {If sName<>Flag}
         Current^.Time:=sTime;           {Initialize all fields}
         Current^.Lat:=sLat;
         Current^.Long:=sLong;
         Current^.Posture:='None';
```

```pascal
                    Current^.Strength:=100.0;
                    Current^.NextMove:=nil;
                    inc(UnitNum[j].NumMoves);

              end;    {If sTime<>Last}
              Last:=sTime;
          end;   {while not EOF}
          writeln('Data Input Complete');
          writeln;writeln;
          NumberofUnits:=j;
      end; {with G}
          close(InFile);
   end; {GraphInput}
```

```pascal
{*************************************************************}
{         Assign Postures from PPpost file                  }
{*************************************************************}
procedure Posture( var g: GraphType);
var i,index          : integer;
  Current            : NodePOINT;
  sTime              : real;
  sName              : string[9];
  sPosture,LastPosture : string[8];
  filename           : string;
  Infile             : text;
begin
    writeln('Input filename for posture data  (MUST be pre-sorted)');
    readln(filename);
    assign(Infile,filename);
    reset(Infile);
    writeln('Reading File....');

    with g do begin
      while not SeekEof(InFile) do begin
        readln(InFile,sPosture,sTime,sName);
        if sPosture<>'INACTIVE' then begin   {Not a valid posture}
        index:=0;
        for i:= 1 to NumberofUnits do begin
          if sName=UnitNum[i].Name then begin {Find unit by index}
            index:=i;
          end;
        end;
        if index<>0 then begin {i.e. a unit has been found}
          Current:=UnitNum[index].FirstMove;
          while (Current<>nil) do begin         {assign current posture}
            if (sTime<=Current^.Time) then begin {up to current time}
              Current^.Posture:=sPosture;
              if LastPosture<>sPosture then begin
                inc(UnitNum[index].PostureChanges);
              end;
              LastPosture:=sPosture;
            end;
            Current:=Current^.NextMove;
          end; {Time Check}
        end; {If index<>0}
        end; {Posture<>Inactive}
      end; {Reading all postures}

    end; {with g}
    close(Infile);
```

```pascal
    end; {procedure}

{*******************************************************************}
{  Procedure to assign the appropriate Strength field entries to each node}
{*******************************************************************}
procedure Strength (var g: GraphType);

var i,index            : integer;
    Current            : NodePOINT;
    sTime,sStrength    : real;
    sName              : string[9];
    filename           : string;
    Infile             : text;
begin
    writeln('Input filename for strength data  (MUST be pre-sorted)');
    readln(filename);
    assign(Infile,filename);
    reset(Infile);
    writeln('Reading File....');

    with g do begin
      while not SeekEof(InFile) do begin
        readln(InFile,sTime,sStrength,sName);
        if sStrength<100 then begin         {only update if needed}
        index:=0;
        for i:= 1 to NumberofUnits do begin
          if sName=UnitNum[i].Name then begin
            index:=i;
          end;
        end;

        if index<>0 then begin

          Current:=UnitNum[index].FirstMove;

          while (Current<>nil) do begin
            if (sTime<=Current^.Time) then begin
              Current^.Strength:=sStrength;
            end;
            Current:=Current^.NextMove;
          end; {Time Check}
        end; {If index<>0}
        end; {If Strength<100}
      end; {Reading all strengths}

    end; {with g}
    close(Infile);
```

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end; {procedure}

```pascal
{***************************************************************************}
{   Prints an adjacency list to a file which shows the movement of each}
{   force over time and its associated posture and strength              }
{***************************************************************************}
procedure  MovesList ( var g: GraphType);
var i     : integer;
   Current: NodePOINT;
   readto : string;
   outfile: text;

begin
  writeln('Input Filename for Location Adjacency List to include Path');
  writeln;
  readln(readto);
  writeln;
  assign(outfile,readto);
  writeln('Writing adjacency list...');
  writeln;writeln;writeln;
  rewrite(outfile);
  writeln(outfile,' Index Name Time Lat Long Posture Strength');
  with g do begin
    for i:= 1 to NumberofUnits do begin
      with UnitNum[i] do begin
        writeln(outfile,i:3,' ',Name);
        Current:=FirstMove;
        while Current<>nil do begin
          write(outfile,' ','-',' ','-',' ');
          writeln(outfile,Current^.Time:5:3,',',Current^.Lat:5:3,',',
              Current^.Long:5:3,' ',Current^.Posture:9,' ',Current^.Strength:5:3);
          Current:=Current^.NextMove;
        end;
      end;
    end;
  end;
  writeln(outfile);
  close(outfile);

end;
```

```
{**********************************************************************}
{    Internal Procedure to execute Distance algorithm provided by Rolands  }
{    and Associates                                                         }
{**********************************************************************}
procedure Distance (Name: string; EnemyMoves,FriendMoves: NodePOINT;
          Flag: integer; var writeto: text);

var Distance,      NautMiles,      EnLatConvert,
    FrLatConvert,  Xdir,           Ydir,
    AngleLong,     ACosArg,        DegDist,
    LastTime,      Time,           LastDistance,
    Closure,       Divisor,        DFCR,
    LastClosure                                    : real;

begin

   if EnemyMoves^.Long=FriendMoves^.Long then begin
     if EnemyMoves^.Lat=FriendMoves^.Lat then begin
       Distance:=0;
     end
     else begin
       NautMiles:=ABS(EnemyMoves^.Lat-FriendMoves^.Lat)*60.0;
     end; {End IF checking Same loc}
   end
   else begin
     EnLatConvert:=EnemyMoves^.Lat/57.29577;
     FrLatConvert:=FriendMoves^.Lat/57.29577;
     Xdir:=COS(EnLatConvert)*COS(FrLatConvert);
     Ydir:=SIN(EnLatConvert)*SIN(FrLatConvert);
     AngleLong:=(EnemyMoves^.Long-FriendMoves^.Long)/57.29577;
     ACosArg:=COS(AngleLong)*Xdir+Ydir;
     if (ACosArg<1.0) and (ACosArg>-1.0) then begin
       DegDist:=(PI/2.0-ARCTAN(ACosArg/SQRT(1-SQR(ACosArg))))*57.29577;
     end
     else begin
       DegDist:=0.0;
     end;
     NautMiles:=DegDist*60.0;
   end; {End IF checking Same E/W loc}
   Distance:=NautMiles*1.8522;
   if Distance>LastDistance then begin
     Divisor:=Distance;
   end
   else begin
     Divisor:=LastDistance;
```

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```
    end;
    if Flag=1 then begin
      Time:=EnemyMoves^.Time;    {Check which elements position changed}
    end
    else begin
      Time:=FriendMoves^.Time;
    end;

    if Time<>LastTime then begin
      Closure:=((LastDistance-Distance)/(Divisor));
      DFCR:=(LastClosure-Closure);
      writeln(writeto,Name,'    ',Time:5:4,
          '   ',Distance:5:3,'   ',EnemyMoves^.Posture,'  ',
          FriendMoves^.Posture,Closure:5:3,'    ',DFCR:5:3,' ',
          EnemyMoves^.Strength:5:3);
      LastTime:=Time;
      LastDistance:=Distance;
      LastClosure:=Closure;
    end;
  end;
```

```
{************************************************************************}
{     Calculates the distance relation between all units and one selected  }
{  unit and all others and writes to output file.                          }
{************************************************************************}
procedure closurecalc (var g: GraphType);

var  LastEMove,LastFMove,
     FriendMoves,EnemyMoves: NodePOINT;
     i,j,Calcs          : integer;
     readto,EnemyName    : string;
     outfile           : text;

begin
   writeln('Select the unit to be analyzed (by index - review adj list');
   readln(j);
   writeln;
   writeln('Input Filename for Distance Data to include Path');
   writeln('NOTE: This file must be separate from Location list');
   writeln;
   readln(readto);
   writeln;
   assign(outfile,readto);
   writeln('Writing distance datafile...');
   rewrite(outfile);
   writeln(outfile,' Unit Time Distance EnPosture FrPosture FCR(t) SA(t)');
    with g do begin
      FriendMoves:=UnitNum[j].FirstMove;
      LastFMove:=FriendMoves;
      for i:=1 to NumberofUnits do begin

        if i<>j then begin
          EnemyName:=UnitNum[i].Name;
          EnemyMoves:=UnitNum[i].FirstMove;

          while FriendMoves<>nil do begin  {for all friendly moves}
                          {and all enemy moves occuring}
                          {before each friendly move}
            while (EnemyMoves<>nil) and (EnemyMoves^.Time<=FriendMoves^.Time)
          do begin
              Distance(EnemyName,EnemyMoves,FriendMoves,1,outfile);
              LastEMove:=EnemyMoves;
              EnemyMoves:=EnemyMoves^.NextMove;
            end;{End IF checking for valid times to calc dist}
            Distance(EnemyName,LastEMove,FriendMoves,0,outfile);
            LastFMove:=FriendMoves;
```

```pascal
          FriendMoves:=FriendMoves^.NextMove;
        end;{End While for Friendly Linked List}
        { if Friend is done moving and enemy is not, continue calc}
        if (FriendMoves=nil) and (EnemyMoves<>nil) then begin
          while EnemyMoves<>nil do begin
            Distance(EnemyName,EnemyMoves,LastFMove,1,outfile);
            EnemyMoves:=EnemyMoves^.NextMove;
          end;
        end;

        FriendMoves:=UnitNum[j].FirstMove;
                          {reset pointer for next enemy}
      end; {End exclusion of i=j }

    end; {End FOR loop }

  end; {End WITH g }

  close(outfile);
end; {Procedure}


begin
end.
```

APPENDIX D. UNIT MOVEMENT ADJACENCY LIST

The following spreadsheet extract is a sample of the adjacency list that is created for every unit in the game after reading the inputs at APPENDIX B.

Index	Name	Time	Lat	Long	Posture	Strength
1	**1-10.ART**					
-	-	3.2	28.367	48.45	DEFEND	99.62
2	**1-11FABN**					
-	-	2	26.4	50.05	DEFEND	99.62
3	**1-12ARRG**					
-	-	2.125	27.009	49.251	MOVING	99.52
-	-	2.125	27.009	49.251	MOVING	99.52
-	-	2.131	27.1	49.187	MOVING	99.52
-	-	2.136	27.151	49.081	MOVING	99.52
-	-	2.142	27.044	49.085	MOVING	99.52
-	-	2.148	26.937	49.089	MOVING	99.52
-	-	2.153	26.83	49.093	MOVING	99.52
-	-	2.159	26.723	49.097	MOVING	99.52
-	-	2.165	26.616	49.101	MOVING	99.52
-	-	2.167	26.578	49.102	MOVING	99.52
-	-	2.172	26.629	48.996	MOVING	99.52
-	-	2.178	26.679	48.891	MOVING	99.52
-	-	2.184	26.786	48.887	MOVING	99.52
-	-	2.189	26.837	48.781	MOVING	99.52
-	-	2.195	26.887	48.675	MOVING	99.52
-	-	2.208	26.824	48.561	MOVING	99.52
-	-	2.214	26.717	48.565	MOVING	99.52
-	-	2.22	26.767	48.46	MOVING	99.52
-	-	2.225	26.763	48.34	MOVING	99.52
-	-	2.231	26.813	48.234	MOVING	99.52
-	-	2.237	26.865	48.124	MOVING	99.52
-	-	2.243	26.972	48.12	MOVING	99.52
-	-	2.248	27.022	48.014	MOVING	99.52
-	-	2.25	27.037	47.98	MOVING	99.52
-	-	2.257	27.09	47.868	MOVING	99.52
-	-	2.262	27.197	47.864	MOVING	99.52
-	-	2.268	27.304	47.859	MOVING	99.52
-	-	2.275	27.416	47.854	MOVING	99.52
-	-	2.285	27.478	47.721	MOVING	99.52
-	-	2.291	27.528	47.615	MOVING	99.52
-	-	2.292	27.521	47.603	MOVING	99.52
-	-	2.297	27.464	47.501	MOVING	99.52
-	-	2.306	27.388	47.366	MOVING	99.52
4	**1-159AVB**					
-	-	1.5	27	49.25	DEFEND	99.93
-	-	2.008	27.091	49.187	MOVING	99.93
-	-	2.012	27.141	49.081	MOVING	99.93
-	-	2.021	27.29	49.075	MOVING	99.93
-	-	2.036	27.362	48.924	MOVING	99.93
-	-	2.042	27.445	48.921	MOVING	99.93
-	-	2.046	27.536	48.857	MOVING	99.93

Units 4 through 23 removed from sample output list

24	10ADBNMX					
-	-	0.001	27.68	45.659	DEFEND	99.51
25	10ARDIV					
-	-	2.548	30.027	47.622	MOVING	99.47
-	-	2.554	29.922	47.626	MOVING	99.47
-	-	2.559	29.816	47.631	MOVING	99.47
-	-	2.566	29.704	47.637	MOVING	99.47
-	-	2.573	29.592	47.642	MOVING	99.47
-	-	2.583	29.495	47.646	MOVING	99.47
-	-	2.599	29.344	47.653	MOVING	99.47
-	-	2.625	29.223	47.811	DEFEND	99.47
-	-	2.897	29.142	47.664	WITHDRAW	94.98
-	-	2.905	29.08	47.551	WITHDRAW	94.98
-	-	2.911	29.128	47.447	WITHDRAW	94.98
-	-	2.917	29.145	47.446	WITHDRAW	95.05
-	-	2.958	29.269	47.44	WITHDRAW	95.12
-	-	2.977	29.35	47.587	WITHDRAW	95.12
-	-	3	29.377	47.529	WITHDRAW	93.84
-	-	3.042	29.426	47.422	WITHDRAW	93.86
-	-	3.083	29.477	47.514	WITHDRAW	93.92
-	-	3.125	29.626	47.507	WITHDRAW	93.96
-	-	3.167	29.705	47.652	WITHDRAW	94.02
-	-	3.208	29.824	47.647	WITHDRAW	94.07
-	-	3.25	29.943	47.641	WITHDRAW	94.1
-	-	3.256	30.049	47.636	WITHDRAW	94.1
-	-	3.261	30.155	47.631	WITHDRAW	94.1
-	-	3.278	30.225	47.476	WITHDRAW	94.1
-	-	3.292	30.347	47.471	WITHDRAW	94.15
-	-	3.298	30.389	47.51	WITHDRAW	94.15
26	10FABN					
-	-	0.001	27.677	46.506	DEFEND	99.55
27	11FABDE1					
-	-	2	26.408	50.072	DEFEND	99.89
28	11FABN					
-	-	0.001	28.177	47.85	DEFEND	99.55
29	12MAR.HQ					
-	-	3	28.367	48.45	DEFEND	99.89
30	12MOTINB					
-	-	0.001	28.476	48.129	DEFEND	99.56
31	13-LANCE					
-	-	0.014	26.443	50.045	None	100
32	13MEU.SO					
-	-	0.02	28.417	48.433	DEFEND	99.5
-	-	2.5	28.433	48.433	ATTACK	99.5
-	-	2.509	28.54	48.357	ATTACK	99.5
-	-	2.533	28.654	48.293	ATTACK	99.5
33	14FABN					
-	-	0.001	28.457	48.13	DEFEND	99.62

APPENDIX E. CLOSURE OUTPUT DATA

The following spreadsheet extract is a sample of the output generated by the closure calculation unit. The example shown was generated using the Iraqi 17th Armored Division as the unit of interest during Run #2 closing on the 1st British Armored Division near KKMC. The second set of tabular data represents the Allied air strike. On inspection it can be determined that the aircraft was on target at 0.6406 and 0.6856 decimal days.

Unit	Time	Distance	EnPosture	FrPosture	FCR(t)	SA(t)	En Strength
1ARDIV.U	0.6009	297.102	MOVING	MOVING	-0.054	0.017	99.46
1ARDIV.U	0.6178	283.256	MOVING	MOVING	0.047	-0.101	99.46
1ARDIV.U	0.625	277.647	MOVING	MOVING	0.02	0.027	99.46
1ARDIV.U	0.6565	264.301	MOVING	MOVING	0.048	-0.028	99.46
1ARDIV.U	0.6667	257.039	MOVING	MOVING	0.027	0.021	99.46
1ARDIV.U	0.7084	254.916	MOVING	MOVING	0.008	0.019	99.46
1ARDIV.U	0.7683	242.342	MOVING	MOVING	0.049	-0.041	99.46
1ARDIV.U	0.7866	226.25	MOVING	MOVING	0.066	-0.017	99.46
1ARDIV.U	0.7917	221.812	MOVING	MOVING	0.02	0.047	99.46
1ARDIV.U	0.81	205.871	MOVING	MOVING	0.072	-0.052	99.46
1ARDIV.U	0.8334	198.873	MOVING	MOVING	0.034	0.038	99.46
1ARDIV.U	0.8421	191.056	MOVING	DEFEND	0.039	-0.005	99.46
1ARDIV.U	2.5	176.799	ATTACK	WITHDRAW	0.075	-0.035	99.48
1ARDIV.U	2.5417	163.495	ATTACK	WITHDRAW	0.075	-0.001	99.48
1ARDIV.U	2.5831	148.022	ATTACK	WITHDRAW	0.095	-0.019	99.48
1ARDIV.U	2.5834	147.942	ATTACK	WITHDRAW	0.001	0.094	99.48
1ARDIV.U	2.6248	132.842	ATTACK	WITHDRAW	0.102	-0.102	99.48
1ARDIV.U	2.625	132.768	ATTACK	WITHDRAW	0.001	0.102	99.48
1ARDIV.U	2.6667	121.554	ATTACK	WITHDRAW	0.084	-0.084	99.48
1ARDIV.U	2.7081	106.936	ATTACK	WITHDRAW	0.12	-0.036	99.48
1ARDIV.U	2.7084	106.829	ATTACK	WITHDRAW	0.001	0.119	99.48
1ARDIV.U	2.7497	93.011	ATTACK	WITHDRAW	0.129	-0.128	99.48
1ARDIV.U	2.75	92.908	ATTACK	WITHDRAW	0.001	0.128	99.48
1ARDIV.U	2.7914	80.305	ATTACK	WITHDRAW	0.136	-0.135	99.48
1ARDIV.U	2.7917	80.174	ATTACK	WITHDRAW	0.002	0.134	99.48
1ARDIV.U	2.833	63.894	ATTACK	WITHDRAW	0.203	-0.201	99.48
1ARDIV.U	2.8334	63.805	ATTACK	WITHDRAW	0.001	0.202	99.47
1ARDIV.U	2.8747	52.491	ATTACK	WITHDRAW	0.177	-0.176	99.47
1ARDIV.U	2.875	52.42	ATTACK	WITHDRAW	0.001	0.176	99.15
1ARDIV.U	2.8826	52.42	ATTACK	WITHDRAW	0	0.001	99.15
1ARDIV.U	2.8883	46.597	ATTACK	WITHDRAW	0.111	-0.111	99.15
1ARDIV.U	2.8939	49.395	ATTACK	WITHDRAW	-0.057	0.168	99.15
1ARDIV.U	2.8996	59.004	ATTACK	WITHDRAW	-0.163	0.106	99.15
1ARDIV.U	2.9052	59.737	ATTACK	WITHDRAW	-0.012	-0.151	99.15
1ARDIV.U	2.9068	73.366	ATTACK	WITHDRAW	-0.186	0.173	99.15
1ARDIV.U	2.9108	73.366	ATTACK	WITHDRAW	0	-0.186	99.15
1ARDIV.U	2.9167	78.632	ATTACK	WITHDRAW	-0.067	0.067	99.15
1ARDIV.U	2.9343	90.489	ATTACK	WITHDRAW	-0.131	0.064	99.15
1ARDIV.U	2.9526	103.744	ATTACK	WITHDRAW	-0.128	-0.003	99.15
1ARDIV.U	2.9584	108.093	ATTACK	WITHDRAW	-0.04	-0.088	99.15
1ARDIV.U	2.9767	122.492	ATTACK	WITHDRAW	-0.118	0.077	99.15
1ARDIV.U	2.995	137.448	ATTACK	WITHDRAW	-0.109	-0.009	99.15
1ARDIV.U	3	141.673	ATTACK	WITHDRAW	-0.03	-0.079	99.15
1ARDIV.U	3.0183	157.104	ATTACK	WITHDRAW	-0.098	0.068	99.15
1ARDIV.U	3.0328	169.932	ATTACK	WITHDRAW	-0.075	-0.023	99.15

Unit	Time	Distance	EnPosture	FrPosture	FCR(t)	SA(t)	En Strength
17AR-280	0.6009	172.244	DEFEND	MOVING	0.402	-0.445	99.53
17AR-280	0.6178	176.985	DEFEND	MOVING	-0.027	0.429	99.53
17AR-280	0.625	179.365	DEFEND	MOVING	-0.013	-0.014	99.53
17AR-280	0.6272	262.207	None	MOVING	-0.316	0.303	100
17AR-280	0.628	246.892	None	MOVING	0.058	-0.374	100
17AR-280	0.6287	231.816	None	MOVING	0.061	-0.003	100
17AR-280	0.6295	217.025	None	MOVING	0.064	-0.003	100
17AR-280	0.6303	202.58	None	MOVING	0.067	-0.003	100
17AR-280	0.6311	188.559	None	MOVING	0.069	-0.003	100
17AR-280	0.6319	175.061	None	MOVING	0.072	-0.002	100
17AR-280	0.6327	162.216	None	MOVING	0.073	-0.002	100
17AR-280	0.6332	146.161	None	MOVING	0.099	-0.026	100
17AR-280	0.634	133.767	None	MOVING	0.085	0.014	100
17AR-280	0.6348	122.466	None	MOVING	0.084	0	100
17AR-280	0.6354	105.81	None	MOVING	0.136	-0.052	100
17AR-280	0.6362	95.707	None	MOVING	0.095	0.041	100
17AR-280	0.6367	78.845	None	MOVING	0.176	-0.081	100
17AR-280	0.6375	62	None	MOVING	0.214	-0.037	100
17AR-280	0.6383	45.186	None	MOVING	0.271	-0.058	100
17AR-280	0.6391	28.45	None	MOVING	0.37	-0.099	100
17AR-280	0.6399	12.099	None	MOVING	0.575	-0.204	100
17AR-280	0.6406	7.228	None	MOVING	0.403	0.172	100
17AR-280	0.6414	22.945	None	MOVING	-0.685	1.088	100
17AR-280	0.6422	22.945	None	MOVING	0	-0.685	100
17AR-280	0.643	23.742	None	MOVING	-0.034	0.034	100
17AR-280	0.6438	34.204	None	MOVING	-0.306	0.272	100
17AR-280	0.6446	48.435	None	MOVING	-0.294	-0.012	100
17AR-280	0.6453	63.975	None	MOVING	-0.243	-0.051	100
17AR-280	0.6461	80.071	None	MOVING	-0.201	-0.042	100
17AR-280	0.6469	96.448	None	MOVING	-0.17	-0.031	100
17AR-280	0.6477	112.989	None	MOVING	-0.146	-0.023	100
17AR-280	0.6485	129.635	None	MOVING	-0.128	-0.018	100
17AR-280	0.649	136.443	None	MOVING	-0.05	-0.078	100
17AR-280	0.6498	153.356	None	MOVING	-0.11	0.06	100
17AR-280	0.6506	170.28	None	MOVING	-0.099	-0.011	100
17AR-280	0.6512	178.761	None	MOVING	-0.047	-0.052	100
17AR-280	0.652	195.7	None	MOVING	-0.087	0.039	100
17AR-280	0.6525	205.235	None	MOVING	-0.046	-0.04	100
17AR-280	0.6533	215.681	None	MOVING	-0.048	0.002	100
17AR-280	0.6541	226.913	None	MOVING	-0.05	0.001	100
17AR-280	0.6549	238.822	None	MOVING	-0.05	0	100
17AR-280	0.6557	251.312	None	MOVING	-0.05	0	100
17AR-280	0.6565	264.301	None	MOVING	-0.049	-0.001	100
17AR-280	0.6565	264.301	None	MOVING	0	-0.049	100
17AR-280	0.6573	268.112	None	MOVING	-0.014	0.014	100
17AR-280	0.6667	268.112	None	MOVING	0	-0.014	100
17AR-280	0.7084	265.895	None	MOVING	0.008	-0.008	100

Unit	Time	Distance	EnPosture	FrPosture	FCR(t)	SA(t)	En Strength
17AR-280	0.8334	210.257	None	MOVING	0.031	0.035	100
17AR-280	0.8421	202.73	None	DEFEND	0.036	-0.004	100
17AR-280	2.8826	193.049	None	WITHDRAW	0.048	-0.012	100
17AR-280	2.8883	183.623	None	WITHDRAW	0.049	-0.001	100
17AR-280	2.8939	179.587	None	WITHDRAW	0.022	0.027	100
17AR-280	2.8996	182.383	None	WITHDRAW	-0.015	0.037	100
17AR-280	2.9052	174.293	None	WITHDRAW	0.044	-0.06	100
17AR-280	2.9108	178.361	None	WITHDRAW	-0.023	0.067	100
17AR-280	2.9167	182.815	None	WITHDRAW	-0.024	0.002	100
17AR-280	2.9343	199.594	None	WITHDRAW	-0.084	0.06	100
17AR-280	2.9526	216.382	None	WITHDRAW	-0.078	-0.006	100
17AR-280	2.9584	221.63	None	WITHDRAW	-0.024	-0.054	100
17AR-280	2.9767	238.424	None	WITHDRAW	-0.07	0.047	100
17AR-280	2.995	255.22	None	WITHDRAW	-0.066	-0.005	100
17AR-280	3	259.881	None	WITHDRAW	-0.018	-0.048	100
17AR-280	3.0183	276.676	None	WITHDRAW	-0.061	0.043	100
17AR-280	3.0328	286.467	None	WITHDRAW	-0.034	-0.027	100

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